A CLASS BOOK OF PHYSICAL GEOGRAPHY

SIMMONS AND STENHOUSE

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OF

PHYSICAL GEOGRAPHY

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PREFACE.

PHYSICAL Geography as a school subject is concerned properly with those aspects of the Earth which determine or influence the life of man. It necessarily touches other departments of natural knowledge at many points, but in the following lessons the contributory sciences of astronomy, geology, meteorology, and physics are introduced only to the extent necessary to make clear some of the more obvious ways in which human life is affected by natural phenomena.

Educationally regarded, Geography is a practical science: practical, since it cannot be studied satisfactorily without the personal performance of observational and experimental exercises designed to lead the student to discover for himself fundamental facts and principles; a science, in that the data with which it deals can be applied convincingly to man's needs only when their place in an orderly sequence of cause and effect is duly appreciated.

The practical exercises set out at the beginning of the various sections of the book have been framed to lead each student to become—within the limits of the course of study—an independent observer able to reason intelligently on the facts he encounters. The descriptive text which follows each set of exercises provides a means of checking the results obtained and the conclusions arrived at by the student. It is urged that, although the descriptive portions of the volume will be found complete as a text-book, much of the educational value of their study will be lost by students who neglect the practical work.

The maps have been prepared to elucidate general principles rather than geographical details, and it is assumed that the book

will be used side by side with a good atlas. An almanac is indispensable for many of the practical exercises; the well-known *Whitaker's Almanac* is sufficiently detailed for the purpose.

A large number of the illustrations are new, and all have been selected to help the reader to understand the text. The authors welcome this opportunity to express their indebtedness to Dr. Tempest Anderson, Dr. W. J. S. Lockyer, and other gentlemen for the use of original photographs, and to Messrs. Macmillan & Co., Ltd., for permission to include illustrations from several of their publications. In the case of figures from scientific journals and similar sources acknowledgment is made under the illustration.

Assistance in framing the scheme of the book has been derived from a study of the syllabuses in Geography of all the principal examining bodies; and the scope has been determined by a consideration of the questions set in recent examinations.

Thanks are due to the authorities of the following examinations for special permission to include at the ends of the chapters the questions which are distinguished by the respective contractions:

C.S., Cambridge Senior Local; C.J., Cambridge Junior; C.S.C., Civil Service Clerkships; C.P., College of Preceptors; Cert., Teachers' Certificate of the Board of Education; Prel. Cert., Preliminary Examination for the Teachers' Certificate of the Board of Education; J.B.M., Joint Board Matriculation of the Northern Universities; L.C.C., London County Council; L.J.S., London University Junior School; L.M., London University Matriculation; N.F.U., National Froebel Union; O.P., Oxford Preliminary; O.J., Oxford Junior; O.S., Oxford Senior; O.H.L., Oxford Higher Local; P.T., Pupil Teachers' Examination.

At every stage in the preparation of the book Prof. R. A. Gregory has placed ungrudgingly at the disposal of the authors his kindly and experienced help, and they find it difficult to express how much they owe to him; their thanks are also willingly offered to Mr. William C. Simmons, B.Sc., for help in reading the proofs and for many useful suggestions.

A. T. S.
E. S.

March, 1912.

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PART I.

MAP-MAKING AND ASTRONOMICAL GEOGRAPHY.

CHAPTER I.

THE MEANING OF A MAP.

1. THE POINTS OF THE COMPASS.

1. Experiments with a pocket compass.—Procure an ordinary pocket compass, lay it flat on the table and examine it. Turn the compass round, still keeping it flat; does the needle move too, or does it remain pointing constantly in one direction? In which direction is the sun about midday? One end of the needle points nearly in this direction, which is called south. Set the compass in such a position that the point marked *S* on the card is just under the south-pointing end of the needle, and consequently that marked *N* just under the north-pointing end. The letter *E* is in the direction of east, *W* of west, etc. Learn also the terms used for the various directions intermediate between these chief "points."

Determine the directions, expressed in these terms, in which several objects in the room lie, relatively to the position of the compass. In what directions do the various windows of the house look? Which of them get the sunshine in the morning, at midday, and in the afternoon respectively? Note the directions of such buildings as can be seen from the windows of the room. Make a note of the directions in which the principal streets in your neighbourhood run.

2. True north.—(*a*) Select a room into which the sun shines at midday. Pin a sheet of drawing paper on a drawing-board, and place the board flat where the sun will shine full on it at midday. If necessary, level the board, that is, render it quite horizontal, by

packing paper under the edge until a steel bicycle-ball does not roll about when placed on the board. Now stick a darning needle upright in the paper at the edge nearest the window. Make sure that the needle is vertical by looking at it from different points of view. About 11.30 a.m., draw an arc of a circle on the paper, taking as centre the foot of the needle and as radius the length of its shadow. At once mark on the arc the point where the end of the shadow cuts it. Notice the slow movement of the shadow over the paper, and when its end once more lies exactly on the arc, mark its position. Now remove the needle, but leave the drawing board in position. Draw straight lines from the centre of the arc to the two marked points on it, and bisect the angle between them. The bisecting line is in the true north and south direction.

(*b*) On another day fix the needle vertically in a different part of the board, and at intervals of half an hour throughout the day (if the sun be shining) make a dot on the paper at the end of the shadow. Join the dots by a smoothly curved line, known as a *shadow trace.* With the foot of the needle as centre draw an arc of a circle cutting the shadow twice. Draw straight lines from the points of section to the centre of the arc, and bisect the angle between them as before to find the north-and-south line.

Which method, *a* or *b*, would you select on a cloudy day? Why?

3. **Error of compass.**—Place your pocket compass on the north-and-south line thus obtained, so that the centre of the compass is exactly on the line. Does the needle lie along the line or at an angle with it? Does the north end point eastward or westward of true north? Estimate, by the help of a protractor, the angle which the needle makes with the line. This angle is called the "magnetic declination."

4. **How to use a watch as a compass.**—Lay your watch face-up on a horizontal surface, and turn it until the hour-hand points to the sun. The hand will then exactly overlie its own shadow. The line bisecting the angular distance between the hour-hand and XII will point southward.

5. **To draw a north-and-south line in the playground.** (*Outdoor work.*)—Using the method of Expt. 2 (*b*) above, mark the shadow trace of the top of a convenient pole. If the end of the shadow be indistinct, mark it as accurately as you can—three or four times at minute intervals—every half hour or so, and in each group take the mean position as the correct point. Draw the circle with chalk held at the end of a cord which is tied loosely to the pole.

6. **How to find the pole-star.** (*Outdoor work.*)—On a clear night look in the northern sky for the group of seven stars called the

Plough, forming part of the Great Bear (*Ursa Major*); identify them by comparison with Fig. 3. Two of these stars are called the "pointers" because an imaginary line joining them passes, if produced, close to the Pole Star. Find the Pole Star. Observe it at different hours of the night and at different times of the year, and notice that it is always in the north, although the position of all other visible stars varies.

The importance of maps.—In every branch of geography constant use is made of diagrams called maps. Most commonly a map represents in a conventional manner a portion of the earth's surface, somewhat as it would be seen by an eye directly above it, but with additions which render it a summary of observations and surveys made on the spot. Such a diagram is of the greatest value, because it enables a student quickly to understand what are the most important features of the region which is being studied, and how these features compare with each other in size and position; besides this, it gives a vivid impression of many other facts which could be only learnt slowly and with much trouble by any other means. It is plain, therefore, that the ability to "read" a map intelligently is one to be cultivated without delay, and there is no surer way by which this power may be acquired than by learning how to construct simple maps.

The points of the compass.—Very little thought will show that in any attempt either to describe or to draw the position of a place, some means of referring to its direction is necessary. We may in ordinary conversation say, for example, that a certain building is on our right, but it is clear that the statement depends on our position at the time, and is true only so long as we remain in that position. When we wish to refer to direction in language which is always true, however, we say that one place is to the north, the south, the east, or the west (as the case may be) of another. This is a much better method, because the statement does not depend on the position of something which may change. How, then, can these directions be recognised?

One of the simplest ways is by the help of a **compass needle.** This is a thin bar of steel which has been made into a magnet, so that when mounted on a pivot it can turn freely in a horizontal plane (Fig. 1).

All magnets, if suspended so that they can move from side to side freely, arrange themselves so that one end, called the north-seeking end, points in the direction of north. The other end of course seeks the south. It is this fact which is made use of in the ordinary compass needle which is used in geographical study for the determination of direction. The line along which the magnet arranges itself is called the **magnetic meridian.**

A person whose face is to the north has his back to the south, his right hand to the east and his left hand to the west. A pocket compass (Fig. 1), such as is sold by opticians, is provided with a card showing the directions of the various "points of the compass" when the north end of the needle is over the letter *N* on the card. Points intermediate between the four principal points have such names as north-east (marked *NE*), west-south-west (marked *WSW*), etc. (Fig. 2), so that it is possible in these terms to express direction with considerable accuracy.

FIG. 1.—A pocket compass.

The **mariners' compass,** though on the same principle, is provided with special means of suspension, etc., to allow for the motion of the ship and other disturbances to which it is subjected.

A more accurate (though not quite so easy) way of determining the points of the compass is by observing **the position of the sun.** Precisely at midday the sun is exactly in the south. Now the moment of midday does not always correspond with 12 noon as indicated by a timepiece; it is sometimes a little before and sometimes a little after twelve o'clock (p. 84). True midday, however, is the time when the sun is highest in the heavens, and this time may be found by observing when the shadow of a vertical post is shortest. At that moment the sun is exactly in the south, and the shadow is thrown exactly to the north. A little before noon the shadow lies towards the north-west; it changes gradually to the north, becoming shorter and shorter; and then, having

passed through the true midday line, works slowly eastwards, becoming longer and longer. The length of the shadow when it lies, say, 10 degrees to the west of true north is exactly equal to the length when, later, it lies 10 degrees to the east of true north; and similarly with any other angle. If, therefore, the direction of the shadow be marked—once before true noon and once after—when it is of the same length, the line bisecting the angle thus obtained will be the true midday line, running exactly north and south. Such a "midday" or north-and-south line at any place is often called the **geographical meridian** of that place.

If a compass needle be placed on the geographical meridian, found in this way, the north end will be seen to point somewhat to the west of true north; but if the extent of the difference—at present, in London, it is nearly 16° W. (Fig. 2)—be remembered, it can always be allowed for. In other words, the geographical meridian does not exactly coincide with the magnetic meridian. The angle between the two meridians is called the **magnetic declination** or **variation** of the place. The value of this angle varies from year to year.

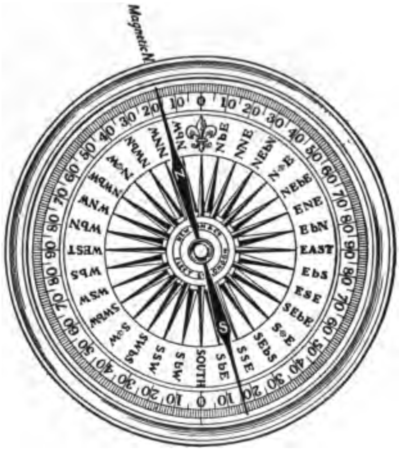


FIG. 2.—To show the "points of the compass," and the magnetic declination at London.

A rough, but often useful, method of finding the points of the compass by means of an ordinary watch also depends on the position of the sun. The watch is laid horizontally, face up, and turned until the hour-hand points to the sun. When so placed, the hand just lies over its own shadow on the dial. The watch being held in this way, a pencil or other convenient rod, placed horizontally so that it bisects the angular distance between XII and the end of the hour-hand, points nearly due south. It would

point exactly south if the sun rose exactly in the east at 6 a.m. and set exactly in the west at 6 p.m. The method is most nearly correct on March 21 and September 23, but is accurate enough for general purposes at any time.

The Pole Star.—On a clear night the points of the compass can be determined easily from the positions of certain stars. A

FIG. 3.—View of the northern sky. To find the aspect of the circumpolar constellations at about 10 p.m. during any season of the year, turn the page until the name of the season is at the bottom.

star called the **Pole Star** lies almost exactly in the north, and for this reason it is often called the North Star. It is not in itself very conspicuous, but it can be found by the help of seven stars which from their arrangement are called the **Plough**, forming part of the **Great Bear** (*Ursa Major*). This group is found in different positions at different hours of the night and at different times of

the year, as is shown in Fig. 3, but two of the stars composing it—called the "pointers"—are so placed that an imaginary line joining them, and produced in the manner shown, passes very close to the Pole Star itself, which by this means is identified readily. All the stars to be seen in our sky by anyone facing north, appear to travel in circles round a point near the Pole Star once in about twenty-four hours, but the Pole Star moves round a circle so small that we may consider it to remain always in the same position, exactly in the north. The stars seen when facing south also appear to be carried across the sky in circular sweeps, but only parts of their paths are visible to us.

2. THE CONSTRUCTION OF PLANS AND SIMPLE MAPS.

1. The plan of a table.—(*a*) Measure the edges of an ordinary rectangular table, and draw on paper a rectangle with sides one-sixth the length of the sides of the table. The drawing is a plan of the table on a scale of one-sixth, or a scale of 2 inches to the foot. Cut out the drawing.

(*b*) Stand a drawing-pin on its head close to one edge of the table; measure the distance of the pin from the nearest corner of the table, and on your drawing make a dot one-sixth of this distance from the corresponding corner, measured along the corresponding side, to represent the position of the pin. Verify the accuracy of the position of the dot, by measuring its distance from the other end of the same side of the rectangle, multiplying by 6, and comparing the length thus obtained with the actual distance.

(*c*) Place the drawing-pin a few inches from the edge of the table, as at *P* (Fig. 4). To represent this position on the plan, lay the drawing on the table so that the point *a* is over the corner *A*, the line *ab* along the side *AB*, and the line *ad* along the side *AD*. "Take a sight" along the surface of the table from *A* in the direction of *P*; make a pencil-dot on the plan exactly between the eye and *P*, and rule a line from *a* through the dot. Now move the plan to the corner *B* of the table, and in a similar manner take a sight of *P* from the point *b*. The intersection of the sighting-lines gives the point *p*, which represents the position of the drawing-pin on the plan.

Notice that in this method of obtaining the point *p*, *a* is placed exactly over *A*, *b* over *B*, and the line *ab* over the side *AB*, so that the "sighting" process is really a method of measuring on the plan the

angles *PAB* and *PBA*. Measure the distances *AP* and *BP* with a tape measure, and see if they are just six times the length of *ap* and *bp*.

(*d*) Move the table, if necessary, until neither pair of sides is in the magnetic meridian, that is, parallel to the compass needle. Draw now a plan of the table in the following manner, to show not only the sides in proportion as before, but also the direction in which each side lies with regard to the points of the compass. First fix a point in a convenient position on the paper, to represent one definite corner of the table. Through this point draw straight lines at right angles to each other and parallel to the sides of the paper. Mark the ends of

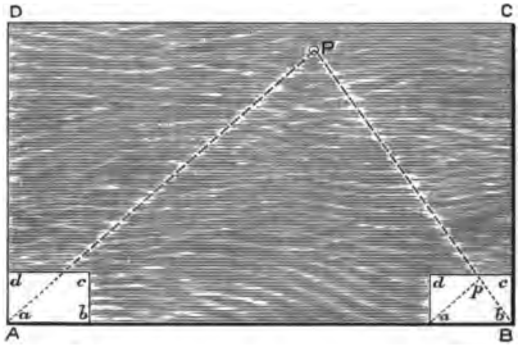


FIG. 4.—Method of drawing the plan of a table. For explanation, see text.

these lines *N*, *S*, *E* and *W* respectively, so as to have the north end of the plan towards the top of the sheet. Using a protractor, estimate as accurately as possible the angle which a side of the table makes with the compass needle, and through the point draw a line making the same angle with the line *NS*. Measure the length of the side in question and (still using a scale of 2 inches to the foot) mark off from the starting point one-sixth of this length on the plan line. This gives the other end of the line representing the first side of the table. Call it the *base line*. The plan of the table itself may be finished by completing the rectangle to scale; but a more instructive way is by "sighting" the remaining corners from the ends of the base line. As a help in sighting, stand drawing-pins at the corners to make their exact positions clear. The sighting method is better, because in using it you obtain the size of each angle in turn, and do not assume that the sides of the table are at right angles to each other.

2. The plan of a room.—(*a*) Draw the plan of a rectangular room, to a suitable scale, by direct measurement, indicating the positions of all corners, windows, doorways and fireplaces. Letter the principal points *A*, *B*, *C*, etc.

(*b*) Draw the plan of the same room, to the same scale, by working from a base line. This may be one edge of a table or desk placed near the middle of the room. First draw the line representing this edge, to scale, and at the correct angle to the magnetic meridian, as before. Then from each end "sight" convenient points to obtain their directions. For sighting it will now be convenient to use a foot-rule through each end of which a flat-headed "carpet-pin" is pushed.* Draw each sight-line, and then measure the distance of the point with a tape, and mark its position on the plan, lettering it at once as in Ex. (*a*). In cases where the tape will not reach the whole distance to be measured, measure along the floor, using a piece of tightened string to be sure you are keeping to the straight line.

Obtain one or two points on the plan by sighting from *both* ends of the base line and trying whether the point of intersection of the two sighting-lines coincides with the point previously obtained by measuring. This is a good test of the accuracy of your work. Notice that by sighting from two points already marked on the plan you can obtain the position of a third point without going to it. You can also find its distance, by measuring the line on the plan and multiplying its length by the scale-number.

3. The plan of a playground. (*Outdoor work.*)—Apply the same method to the drawing of a plan of a playground. First, chalk off a base line, using stretched string to obtain a straight line. If convenient, let the base line lie in the magnetic meridian. On the base line measure a convenient length (in links, feet or metres according to the divisions of the measure you use) with either a steel band measuring chain, an ordinary land chain (Fig. 5) or—failing these—metre or yard rods (put end to end) or tapes. Draw the plan on paper pinned on a drawing-board mounted on a camera-stand or supported by a strap over the shoulder. Properly made "plane tables" (Fig. 8) for such work may be obtained from opticians and scientific instrument makers. Decide carefully on a suitable scale before beginning. Obtain directions either by the sighting ruler suggested in Ex. 2 (*b*) above, or by

* Vertical needles, pushed into the upper surface of the ruler may be used instead if the pin heads cause the ruler to wobble. A better sighting arrangement, easily made, consists of a vertical needle at the far end of the ruler, and at the sighting end a vertical strip of cardboard, sheet zinc or tin, in which a vertical slit has been cut in the manner shown in Fig. 8.

more accurate apparatus.* Be careful that whenever a "sight" is being taken, the needle of the compass lies exactly over the *NS* line on the paper. Draw each sight-line as soon as its direction has been obtained, and at once measure the length by careful pacing (having previously determined the average length of your stride by pacing a measured distance in the playground), and mark it to scale on the plan. As in the previous exercise, obtain the positions of some of the points by the intersection of sighting-lines; after a little practice this method will be found to give better results than pacing.

4. A simple map. (*Outdoor work.*)—Select a suitable small area in your neighbourhood, preferably diversified in character and with numerous objects—*e.g.* trees, stiles, corners of buildings, etc.—which can be used for sighting purposes. Measure a base line with a land chain (Fig. 5), and drive one of the arrows or a post (*e.g.* a cricket

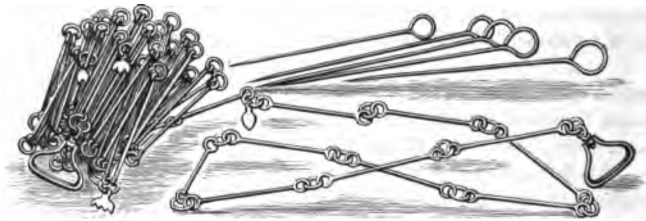


FIG. 5.—A surveyor's land-chain and "arrows."

stump) vertically into the ground at each end of the base, putting the post at one end just inside the handle of the chain, and at the other just outside. Before beginning the drawing, estimate roughly the size of the area to be represented, and then decide on a scale which will allow it to be included on the paper. Find the direction of the base by means of the compass, and then draw it to scale and making the proper angle with the *NS* line on the paper. Be careful to draw the base line in such a position that, with the scale selected, sufficient room will be left on all sides for the drawing. As before, be careful that the compass, laid on the

* Accurate measurements of the angle between two distant objects can be made by using either:

(1) A prismatic compass—a combination of compass and sighting ruler sold by instrument makers.

(2) A sextant: a simplified form of sextant known as the *Anglemeter* is sold by Messrs. W. & J. George & Co., 157 Great Charles Street, Birmingham, for 2s. 9d.

(3) A theodolite: a *School Theodolite* giving excellent results may be obtained from Mr. W. B. Nicolson, 54 Hill Street, Garnethill, Glasgow, for 35s., or from Messrs. J. J. Griffin & Sons, Ltd., Kingsway, London.

paper, lies parallel to your *NS* line when a sight is being taken. It is obvious that any line, once represented accurately on the map, may be taken as a base for further observations, and that the positions and distances of inaccessible, but fairly near, objects may be obtained by the intersection of sighting-lines. Determine a few such distances; obtain, *e.g.* the width of a river by sighting an object from two points on the opposite bank.

When the positions of a large number of points have been obtained, the outlines of walls, streams, etc., may be drawn in by freehand. With dividers measure on the plan the length between any two points; calculate from the scale the real distance to which this corresponds, and then test your result by pacing.

5. The parish plan.—Obtain, if possible, the "parish plan" of your neighbourhood, published by the Ordnance Survey. This is on a scale of 1/2500, *i.e.* 25·3 inches to a mile. Examine it carefully, and compare it with the map you have made. With dividers and a steel rule measure the distances between several familiar points on the plan, and multiply by 2500 to get the real distances.

6. The six-inch map.—If the local Ordnance Survey sheet on a scale of 6 inches to a mile can also be obtained, compare the parish plan with it, noticing the difference in size of the representation of your neighbourhood. Take the map to the highest point accessible in the district (*e.g.* a church tower), and identify as many as possible of the features marked on it.

Do not, for the present, pay much attention to any heights marked on the plan and map, but, after finding your own position, observe carefully the direction and distance of each well-marked feature of the landscape. Estimate the distances, and check your estimates by reference to the map. Also, observing that on the parish plan one square inch represents approximately one acre, estimate the areas of neighbouring fields.

The broad principles of map-drawing.—Since a map is to represent in miniature a portion of the earth's surface, it must not only show the directions in which the various features of the landscape lie with regard to each other, but it must also display them in correct proportion as to size and shape. Let us suppose, as an illustration, that a rectangular field is 150 yards long and 100 yards wide, and that the two long sides, *AB* and *DC* (Fig. 6), run in a north-easterly direction. It would not be sufficient for a map of the field to show merely that *B* was to the *NE* of *A*, *C* to the *SE* of

B, *A* to the *NW* of *D*, and so on; for these facts might be true of a field having a quite different shape. The map must also show the proportionate length of the sides of the field; that is, the sides *AB* and *CD* must each be shown as having $1\frac{1}{2}$ times the length of *BC* or *DA*. The sides *AB* and *CD* might, for example, be drawn $1\frac{1}{2}''$ long, and the sides *BC* and *DA* each $1''$ long. The drawing would in that case represent the field on a scale of one inch to 100 yards.

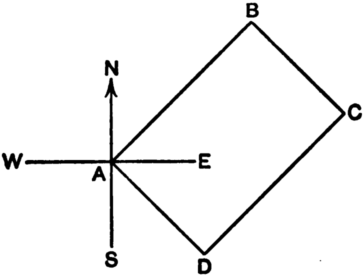


FIG. 6.

Fences or other lines at right angles are recognised fairly easily as such, and to draw them in plan is a matter of no great difficulty. For, when the direction of one line has been found by the compass, any other information necessary can be obtained readily by measurement with a tape or chain, or by pacing.

In work on map-drawing from nature, however, lines meeting at unknown angles are always found, and the representation of these requires special care. Let us take as an instance a field enclosed by straight fences, and having the shape shown in Fig. 7. A plan or map of such a field is begun by marking, upon a sheet of paper pinned on a drawing-board, a dot in a convenient position to represent, say, the corner *D* of the field. Through this point is drawn a straight line, parallel to the side of the paper, to represent the magnetic meridian of the point. The upper end of the line is marked *N*, the lower end *S*. Next, the surveyor, standing at the corner *D* of the field, places a pocket compass on the paper so that its centre is over the line, and turns the drawing-board so that the needle itself lies along the meridian line *NS*. A "sighting-ruler" is now laid carefully along the paper,

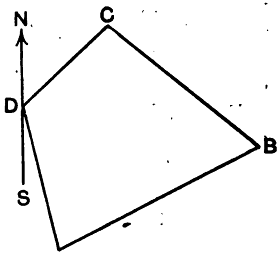


FIG. 7.

pointing from the dot, in the direction first of the fence *DC* and then of the fence *DA*, and a straight line is drawn to represent each. The lengths of the fences are ascertained by pacing, and are marked on the lines to some convenient scale. The points *C* and *A* are thus obtained. The remaining point *B* may be determined in a similar manner from either *C* or *A*, the length of the fence being measured by pacing as before. After preliminary exercises of this kind, it will be found that the positions of distant points are best determined by the intersection of sighting lines drawn from the ends of a carefully measured base.

Such survey work is facilitated by having the drawing-board—technically known as a *plane table* (Fig. 8)—mounted on a tripod

Fig. 8.—Sight-rule on plane table.

stand, or suspended by a strap from the shoulders. In the latter case two students may with advantage work together: one ensuring that the *NS* line is kept parallel to the compass needle, whilst the other ascertains the directions of distant objects by "sighting" along the surface of the board. To aid in correct sighting, it is useful to fix an ordinary pin at the point on the paper which represents the position of the observer, and to use a second pin to mark a point exactly between the first and the sighted object. It is better to use a proper *sighting-ruler* (Fig. 8), or prismatic compass (a combination of sighting-ruler and compass); simple substitutes are described on pp. 9 and 10.

An object may be sighted from each end of a carefully measured base line in this way, and the intersection of the two sighting-lines

will give the position of the object on the plan. Its distance may now be found by measuring the line on the plan and multiplying by the necessary factor. Actual measurement along the ground is thus unnecessary if the observations have been made carefully. The length thus obtained may now be used as a new base line, and further observations made from its ends. The features between the points are then carefully filled in, and a complete map of the surface features of the district is thus obtained.

This is essentially the principle upon which maps of a country are actually drawn, although in accurate work great refinements are necessary at every stage—in finding the meridian, and in measuring both the base line and all angles.

The beautiful maps published by the Ordnance Survey are examples of the best work of this kind; and the student is recommended to study very carefully all the Ordnance maps showing his own district, comparing them whenever possible with the actual features of the landscape.

EXERCISES ON CHAPTER I.

1. Mention the essential parts of a plane table, and the use of each. Describe how you would, by its means, make a map of the hall in which you are seated.

2. A boy wishes to make a plan of the cricket field at his school, showing the position of the pitch. He has a mariner's compass and a tape measure. The field is level. Describe fully how he may proceed. (C.S.)

3. How would you proceed to prepare a plan of a four-sided (but not rectangular) field with a chain or tape measure, but without any instrument for measuring angles?

4. Describe two methods by which you could lay down a line running east and west through a given point on the earth's surface. (C.J.)

5. Explain any method by which you could draw a map of a small level district (such as a park or recreation ground) with some degree of accuracy. (C.S.C.)

CHAPTER II.

THE MEANING OF A MAP (*Continued*).

3. SURFACE RELIEF.

1. Comparative height. (*Outdoor work.*)—Walk over the local area you have mapped previously and try to discover which of the points shown is highest, which lowest, etc. Mark the lowest point *a* on the map, the next higher *b*, and so on. When there is any doubt as to the comparative heights of two points, look from one to the other along the surface of water in a tumbler or, better, in a U-tube or water-level (Fig. 9). If the slope of the ground is too gentle for even this to be of use, notice which way the water flows in rainy weather. Observe the direction of the flow by means of a compass, and indicate its direction in as many places as possible on the map.

FIG. 9.—A simple water-level and levelling staff used for measuring relative heights.

2. The measurement of height. (*Outdoor work.*)—Take either a levelling staff, or a six-foot wooden rod graduated in inches (Fig. 9), to the lowest point shown on your map. Carefully holding the rod vertical, observe the height at which the water-level (tumbler or U-tube) must be held so as to be on the same level as the point next higher (*b*). Mark this height on the map.

In the same way find how much higher *c* is than *b* and note it on the map. Do the same with all the other points.

3. **The modelling of surface relief.**—Copy your map on cardboard, and at each point of which you know the relative height push—up to its head—a slender pin vertically through the cardboard from below. Decide on a suitable scale of heights, say 10 feet to one inch. Cut each pin to the proportional height with a wire-cutter, and then make a model of the area in wet sand, modelling clay or plasticine, using the pins as guides. If the heights of the model appear exaggerated, cut the pins down to a smaller scale and repeat the exercise until the heights seem reasonably represented. Compare the vertical and horizontal scales. If convenient, take a photograph of your model, lighted from one side.

4. **The measurement of slope.**—(*a*) *A clinometer.*—Make a protractor in cardboard, but in numbering the scale take the usual position of 90° as zero. Prick a hole through the centre point and pass through it, and secure, by a knot, a piece of thread the other end of which carries a small weight (*e.g.* a boot button). Gum the protractor accurately along one edge of a school slate or other rectangular frame, as shown in Fig. 11. This is a simple form of clinometer.

(*b*) *Outdoor work.*—Measure the slope of the ground in various steep places by holding your clinometer in a vertical plane with the base line parallel to or on the ground and reading the position of the thread on the scale. A slope of 1° corresponds to a rise or fall of 1 in 57·3, *i.e.* 1 foot in about 19 yards. How does your scale-reading, thus interpreted, agree with the heights shown on your map? Write on your map, along the directions of slope previously obtained by observing the flow of water, the approximate gradients, *e.g.* 1 in 19, 1 in 11, etc.

5. **Gradients of roads.** (*Outdoor work.*)—Estimate the gradients of any sloping roads in your neighbourhood, first mentally and then by using both the angular measurement and the water-level and levelling-staff method. In pacing distances count your steps both up and down the slope and take the mean. Do you find you have a tendency to exaggerate the gradient mentally? It is said that "heavy waggons cannot go up a slope steeper than 8° without extra horses." If possible, find whether this statement holds good for your district.

6. **Slope expressed by shading.**—Shade a copy of your map, very lightly on slight slopes and to varying degrees of darkness according to the steepness of the ground. Leave all the flat (*i.e.* horizontal) ground unshaded. Compare the shaded map with the photograph of the model, if one was obtained.

The surface relief of the land.—A map showing merely the distances and directions between the various points indicated—as if all these points lay on a perfectly flat surface—gives, in most cases, a very inadequate idea of the real nature of the district. The sculpturing of the surface into more or less pronounced hills and dales is, as we shall see later, of the deepest significance, and it is necessary that such surface-relief should be recorded on maps. This might be done, roughly, by conventional signs showing which point was lowest, which was next in height, and so on. In a student's sketch map the lowest point shown might be marked *a*, the next higher point *b*, the next *c*, for example.

FIG. 10.—Water-level. Ordnance Survey pattern.

Such a comparison of heights is made easily by looking along any horizontal surface from one point to another. A simple and convenient means of obtaining a horizontal surface is a fairly large U-tube, such as is used in laboratories. Water is poured into the tube and, of course, stands at the same horizontal level in both limbs. Holding the tube so that he looks along the surfaces of *both* columns of water, an observer sees at once whether any distant object is higher or lower than his eye. As a simpler form of "water-level," water in a tumbler may be used in the same manner, but it is not so easily carried in the field, and has the further disadvantage of not affording so extended a horizontal surface. In more accurate survey work a water-level like that shown in Fig. 10 is often employed. Over ground which is too flat to be tested conveniently in this way, or of which the slope is imperceptible to the eye, the direction of flow of rain water plainly shows on which side the higher land lies. Indeed, whatever the extent of the slope, its direction may be discovered

easily by the flow of water and, after comparison with the compass, may be indicated on the map.

The measurement of relative heights.—With the help of levelling staves or other graduated rods (Fig. 9), it is easy to extend the use of a water-level to the measurement of the extent by which one point is higher than another. Taking up his position at the lowest point, the student arranges his water-level alongside the vertical staff at any convenient height (say 5 feet), which is noted, and looks along the level to another graduated staff held vertically by an assistant at the next higher point *b*. If the water-level is seen to be at the same height as the 2 ft. mark on the staff at *b*, the point *b* is evidently 3 ft. higher than the point *a*. From *b* an observation of the height of *c* over *b* is next taken, and the process is repeated from point to point until all the relative heights are known.

In official surveying, the *level* usually consists of a telescope provided with a spirit level and mounted on levelling screws on a tripod. The instrument is placed between two staves, one of which is further up and the other further down the slope. The reading of the level on each staff is taken in turn, the difference being the difference in height of the ground between the staves. The level and the back staff are then moved in front of the front staff, which is kept in the meantime in the same position, and another pair of readings is taken. The process may be repeated for miles.

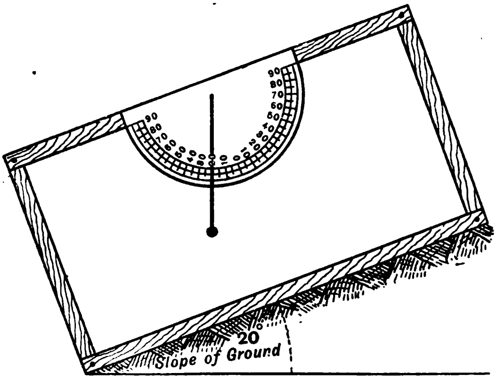


FIG. 11.—A simple clinometer (p. 16).

The measurement of slope.—Knowing both the distance and the difference in height between two points, it is easy to calculate the average slope, or gradient, from one point to the other. A gradient of 1 in 57·3, that is, 1 foot in 19·1 yards, corresponds to a slope of 1 degree. The student will find it instructive to determine the gradient of the steepest roads or paths in the district, and to notice how much smaller, in general, is the inclination than the untrained eye would have estimated it to be.

As a matter of fact, macadamised roads are now rarely made with a greater slope than 1 in 40, and paved roads as a rule have a still smaller gradient. A rough idea of the angle which a steep path makes with the horizontal may be obtained by so holding a protractor (mounted as in Fig. 11)—from the "centre point" of which hangs a weighted thread (plumb line)—that while its plane is vertical the base line is parallel to or actually on the ground. For accurate determinations an instrument called a **clinometer,** constructed essentially on the same principle, but provided with a means of "sighting" along the base line, is used. A simple form of clinometer is shown in Fig. 11.

The modelling of surface relief.—When the relative heights of the points marked in the student's map have been measured in

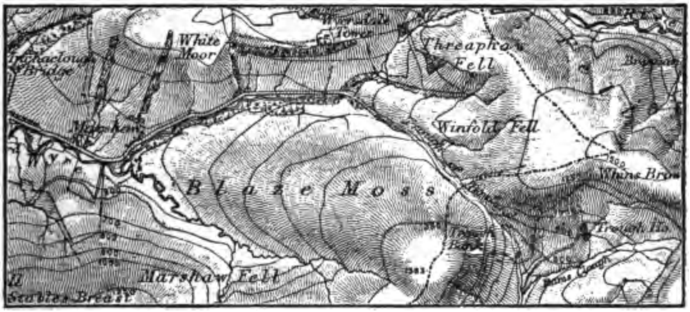


FIG. 12.—A hachured and contoured map. A portion of Sheet 59 of the Ordnance Survey one-inch map. Scale 1″=1 mile. (Compare with Fig. 15.)

the manner described, they may with great advantage be represented to scale by a model in damp sand, clay, or plasticine, built up on a sheet of cardboard. Unless the district be very hilly it will as a rule be found necessary to employ a larger vertical scale than the horizontal scale, in order to obtain a realistic effect. This fact illustrates the tendency of most people to exaggerate mentally the heights of elevated parts of the scenery, a tendency which it is well to bear in mind.

Hachures.—A carefully constructed model of this kind may be taken as a guide in an attempt to represent, by shading a flat map of the same district, the "ups and downs" of the surface. In such work it is usual to leave flat parts unshaded, and to graduate the depth of shading according to the steepness of the slope.

Fig. 12 shows a map shaded on this principle. The details of the shading, however, have a further significance, for the lines employed—called **hachures**—are not only thickest and closest together where the slope is greatest, but they are drawn in the *direction* of the slope, and so represent also the general direction in which water would flow over the surface if free to choose its own path. The chief advantage of hachured maps is that they convey, at the first glance, a general idea of relative steepness. A drawback to their use is that the shading often interferes with the legibility of the lettering and may also obscure other details. In the newer one-inch survey maps, hachures are done in colour to obviate this difficulty.

4. CONTOURS.

1. A plasticine model.—In the bottom of an ordinary wash-basin make in plasticine a model of a more or less imaginary landscape—including a mountain with two peaks of different heights, smaller hills, and a few valleys running into one main valley. Let the lowest part of the model be at one side and about $\frac{3}{4}$ of an inch from the bottom of the basin, and let the summit of the highest peak be a little below the level of the rim. Stick a graduated ruler vertically into the plasticine at the lowest part of the model.

Having placed the basin in a suitable position, hold a fine-rosed watering-can over it until water has collected in the basin up to the level of the first inch mark of the ruler. Suppose this to be sea level. Make a careful drawing—natural size—of the outline of the edge of the water (the shore line). Now add water from the can as before, holding it well up, so that the "rain" will be as fine as possible. Observe carefully how it flows off the heights in various directions, how the small streams unite to form rivers in the valleys, how these join to form a larger river which discharges into the sea. Continue watering until the level has risen to the second inch mark on the ruler. Now make a drawing of the edge of the water on the same paper as before, measuring if necessary with blackboard compasses from the ruler or from marks on the rim of the basin. Mark this outline "100 feet contour."

Continue the process until the highest peak alone is left as an island above the water, stopping to draw the contour lines as the water reaches each successive inch mark, and numbering each line in hundreds of feet as soon as drawn. What is the general shape of a

contour in a narrowing valley? In what directions are the contours crossed by rivers (*a*) in narrowing valleys, (*b*) elsewhere?

Finally, add water to the top of the peak, read its height on the ruler, and note it on the map. Now siphon off the water; one or more pools (lakes) may be left in the valleys. Carefully compare your contoured map with the model itself. Notice that where the slope is steepest the contours are nearest each other; where the slope is gentle they are far apart.

2. Hachures.—Copy the map of your model landscape (Expt. 1) on a smaller scale, and shade it by hachures (p. 19). Remember that hachure lines are in the direction in which water would flow, and that this direction is in most cases at right angles to the neighbouring

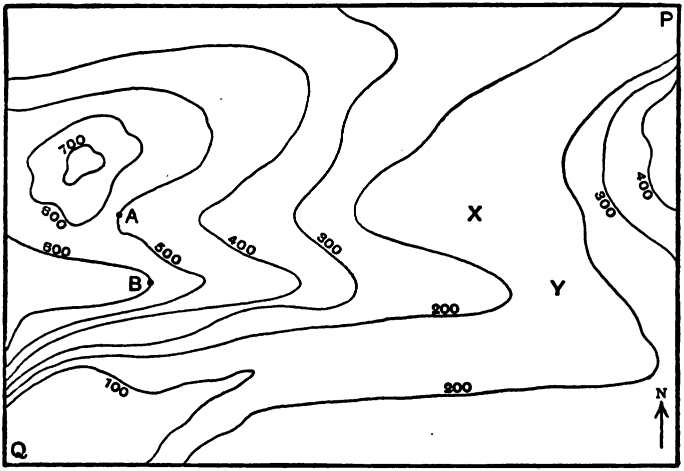


FIG. 13.—Map to illustrate Ex. 3, Section 4.

contour line (Expt. 1). Draw the hachures thickest and closest together where the slope is greatest, *i.e.* where the contours are closest.

3. General exercises on contours.—(*a*) In Fig. 13 the contours are marked in feet and the scale is one inch to a mile. Suppose yourself to be walking for $1\frac{1}{2}$ miles due east from *A*; how does the ground slope (i) behind, (ii) in front, (iii) on your left, (iv) on your right? What name would describe the character of the surface between *A* and *X*?

Answer similar questions with respect to a walk from *B* to *Y*.

In what directions would water falling at *A* and *B* respectively flow?

Imagine yourself to be walking from *P* to *Q* along the lowest ground

you can find; what is the approximate length of the route? Briefly describe the view to be seen at intervals of a mile.

Where is the steepest ground shown on the map?

Copy the map and shade it by hachures.

(*b*) Represent by numbered contours (i) a deep valley with a slope of 50 feet per mile; (ii) a shallow valley with a similar slope; (iii) a hill 75 feet high with a slope of 60 feet to the mile on the north side and 40 feet to the mile on the south (10 feet contours); (iv) a pass running north-east, at a height of 1200 feet, between two peaks 1650 and 1400 feet high respectively.

4. Contoured map of the neighbourhood. (*Outdoor work.*)—Take your stand at the lowest point of the area you have previously surveyed, and, sighting with the water-level at a height of 5 feet, signal to a companion where to peg pieces of paper, or otherwise to mark points, at this level. Obtain the positions of these points on your map in the usual manner, and through them draw the 5 feet contour line (considering the lowest point as zero). Next obtain the 10 feet contour by working similarly from a point on the 5 feet line, and continue until the highest point is reached. Where the ground is irregular the marked points should be placed closer together.

5. Cardboard model of neighbourhood.—Duplicate your contoured map so as to have at least as many copies as the number of contours shown. Paste one map on cardboard; cut out from a second map the area enclosed by the 5 feet contour line, from a third that enclosed by the 10 feet line, and so on with each contour. Then paste each on a separate piece of cardboard, and cut the cardboard to the outline with a sharp penknife or a fret-saw. Build up the model by gumming the contour segments in position on the complete map. When the gum is dry the "terraces" of the model may be smoothed off, if desired, with putty or plasticine.

(*b*) Repeat the exercise, using 1-inch Ordnance maps of your district if the slope is very gentle. These maps can now be bought at cheap rates for school purposes from the Ordnance Survey Office, Southampton. Mount one or two maps of the district with the aid of thin glue on cardboard about one-twentieth of an inch thick. For a hilly district the 6 inch contoured maps should be used. With a fret-saw cut through the even hundred contour lines of one map and through the odd hundred contour lines of a second map. Thus obtain pieces of cardboard or fretwood, which can be glued one above the other to build up a relief map of the district. The chief features of the map can be accentuated on the model.

6. Aneroid barometer. (*Outdoor work.*)—Procure an aneroid

barometer (Fig. 19); read the dial at the bottom of the highest accessible building and then immediately take it to the top of the building, tap it *gently*, and notice to what extent the position of the index has changed.

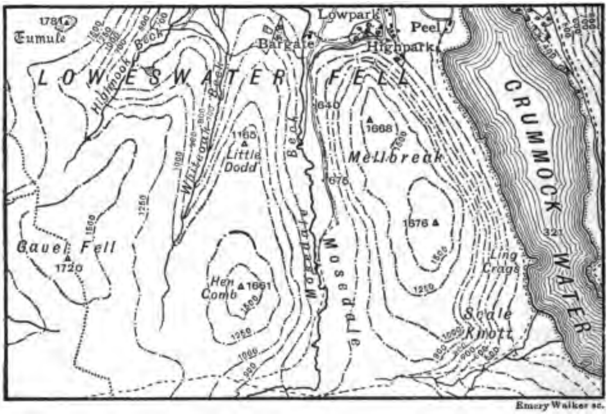
Contours.—Although hachured shading (p. 19) gives a very effective representation of the general steepness and direction of slope of the land, it does not afford any information respecting actual heights. These and many other features are best shown by what are called contours. A **contour** is defined as "the representation on a map of an imaginary line joining all immediately adjacent points which are the same height above mean sea level."*

Thus a line on a map, joining all adjacent points at a height of 100 feet above mean sea level, is called the 100 feet contour. We may imagine it to show where the shore line would be if the sea were to rise 100 feet above its present normal level. On steeply sloping land the new shore line would not be far—as seen from above—from the present position of the edge of the water; but on a gentle slope a height of 100 feet would only be reached at a considerable distance from the present shore. Similarly, if the sea were to rise still another 100 feet, the edge of the water (the line of the 200 ft. contour) would be at a distance from the 100 ft. line which would depend upon the steepness of the land between them.

Some typical contour-patterns.—Exercising the imagination in this manner, it is easy to form, from a contoured map, a mental picture of the configuration of the ground. Some of the most commonly occurring patterns of contour lines are shown in Figs. 14 and 15, which are worth careful study. The contours are marked at vertical intervals of 100 feet up to a height of 1000 feet. Above that they are shown at intervals of 250 feet. The horizontal scale of both maps is 1 inch to the mile. In Fig. 14, it will be noticed that within ¼ of a mile the land rises from 321 feet (the height of Crummock Water above sea level) to a height of 1250 feet—a slope of 3700 feet per mile. Ground so steep as this is called a **crag**. The mountain of Mellbreak has two **peaks**, each indicated by a closed curve. The positions and altitudes of the summits of the peaks are marked separately; if they were not

* Lt.-Colonel Close's *Text Book of Topographical and Geographical Surveying* (Wyman), 3s. 6d.

so distinguished we should conclude that each peak was flat topped at the level of the last contour (1500 feet). On the west of Mellbreak is a valley (Mosedale) down which Mosedale Beck flows to the north. To the west of Mosedale is the hill Little Dodd, culminating in Hen Comb (1661 feet). Little Dodd in its turn is separated by a valley with its stream (Whiteoak Beck) from another eminence—Gavel Fell. The V-shaped contours of the



Emery Walker sc.

FIG. 14.—Copy of a portion of Sheet 29 of the Ordnance Survey one-inch map. Scale, 1 in. = 1 mile.

valley between Little Dodd and Gavel Fell are very obvious, and contrast with the reverse contour-pattern of the **ridge** immediately to the eastward.

Fig. 15 is a map of a small portion of country ten miles to the E.S.E. of Lancaster. The stream flowing north-west between Blaze Moss and Marshaw Fell is a tributary of the River Wyre. It is joined at Marshaw by another tributary flowing W.S.W. from Threaphaw Fell. The V-shaped contours indicating the **converging valleys** down which the various streams flow are shown clearly. The Trough of Bowland (Fig. 16) is a **pass** over the **saddle** between Winfold Fell (rising to over 1500 feet at Whins Brow) and Blaze Moss (which reaches a height of 1383 feet). The highest point of the road is plainly between 900 and 1000 feet above sea level. Here the road is crossed by the boundary

between Lancashire and Yorkshire. This follows the high line or watershed separating the tributaries of the R. Wyre from those

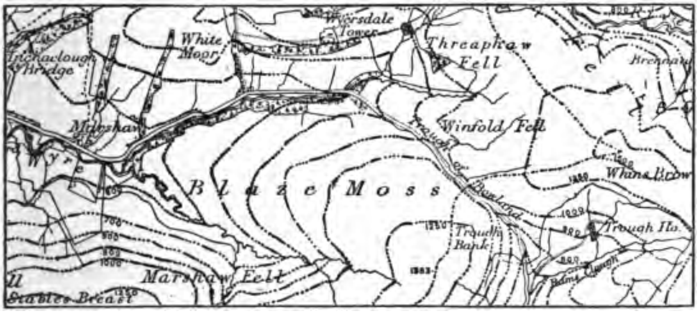


FIG. 15.—A portion of Sheet 59 of the Ordnance Survey one-inch map. Scale, 1″=1 mile. (Compare with Fig. 16.)

of the R. Hodder to the south of the area mapped. The Trough of Bowland is an excellent example of a **gap** affording communication between valleys on opposite sides of a range of mountains.

FIG. 16.—The Trough of Bowland, seen from the south. The hill on the left is Trough Bank. (Compare with Figs. 12 and 15.)

Having followed the description now given with the aid of the map, the student would do well to proceed in the reverse order.

Without referring to the map, he should draw a sketch map showing contours embodying all the facts given in the description. It will be easy, by comparing the completed sketch with the map, to see how far he has understood the map itself.

In the drawing of a contoured map from a given description of the topography of a district, the relative positions of the features mentioned should be first sketched lightly on the scale given. Any heights furnished should be marked next, and the contours put in last of all. In the contouring the most important facts to be remembered are:

(1) Contours are close together on steep ground, as on cliffs and crags, but are far apart on gently sloping ground.

(2) The contours both of isolated peaks and of depressions surrounded on all sides by higher ground are concentric curves, the heights increasing towards the centre in the former and decreasing in the latter case. Isolated depressions are rare except when filled with water, when they form lakes.

(3) Both valleys and sloping ridges are indicated by V-shaped contours. In the former case the angles of the Vs point towards the higher ground; in the latter they point to the lower ground. The angles are greatest in the most rapidly narrowing valleys, and least where the sides are most nearly parallel. The angles are closer together in steep valleys than in valleys with gently sloping beds.

(4) Rivers flow only in valleys, connecting the angles of the Vs.

Methods of contouring in the field.—It is a comparatively easy matter to find a number of points on the same horizontal level and, after marking the positions of such points on a map (in the manner described in Chapter I.), to draw a contour line passing through them. **In making ordinary sketch maps** the water-level and levelling staff (Fig. 9) would be employed for this purpose, the observer signalling to an assistant at a little distance where to place a conspicuous mark. The observer would then move to the marked station and fix a third point in a similar manner. By continuing the process, points sufficient in number to fix the contour line correctly would be marked. In very accurate work more refined instruments on the same principle are, of course, employed.

In a student's sketch map the first contour might conveniently be drawn in this way through all points five feet above the lowest level on the map, which might be regarded as of zero height, and succeeding contours might be found by working similarly from a point on the first contour.

In ordnance surveys, however, the assumed mean level of the sea at Liverpool—known as the **Ordnance Datum** (O.D.)—is taken

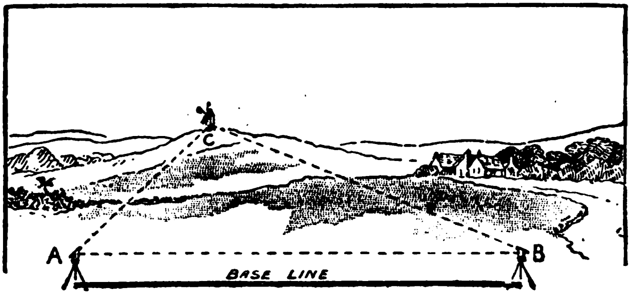


FIG. 17.—Surveying from a base line.

as zero, and it is necessary, as a preliminary to contouring, to fix on a starting point at some definite height above sea level.

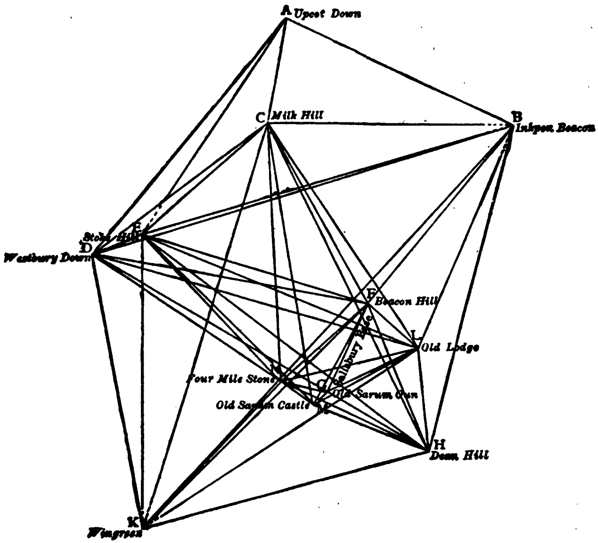


FIG. 18.—The early stages of the triangulation of England.

This may be done in various ways. One way is to work up from sea level by determining in succession the heights of conspicuous

objects (*e.g.* cairns on hill tops, the summits of church spires, etc.) above sea level. For this purpose the angles which the directions of such objects—sighted with a theodolite—make with the horizontal are measured (Fig. 17), and the heights are calculated by trigonometry. By an extension of this process, a system oi triangles is built up, fixing the precise positions and heights of a large number of points. This is called the method of **triangulation.** Fig. 18 shows the earlier stages of the triangulation of England from a measured base-line on Salisbury Plain.

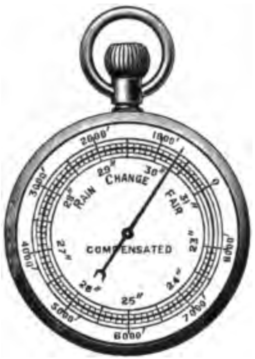


FIG. 19.—A pocket "aneroid" barometer.

Another, though less accurate, method which is often used for finding heights depends on the fact that, if the atmospheric conditions remain constant, a barometer carried from a low to a higher level registers a regularly diminishing pressure of the air. For small elevations it is said that a fall of one inch in the barometer-reading corresponds to an increase of about 900 feet in altitude (Chapter XIV.). Fig. 19 illustrates an "aneroid" barometer used for measuring in this way the heights of mountains. The inner circle shows, in inches, the "height of the barometer," which depends (Chapter XIV.) on the pressure of the atmosphere; the outer scale shows in feet the differences in altitude corresponding roughly with these changes.

The heights of a number of points having been obtained by preliminary work of this kind, each point is marked by a **Bench Mark** —a broad arrow with a horizontal line through the point —cut on a stone wall, strong fence or other suitable fixed object, and the actual heights above the Ordnance Datum line are noted in feet and decimals of feet upon the 6 inch maps with arrows to show the exact positions of the bench marks. Then the contours are drawn from these marks. For example, if a bench mark is found on the 6 inch map and the height is given as 95·56 feet, the staff is fixed with its lower end on a level with the horizontal part of the bench mark and the levelling instrument is set up. A reading is taken of the mark on the staff which corresponds with the height of the level. Suppose it is 5·2 feet. Then to get the 100 feet contour the staff must be moved up the hill until the man at the instrument reads 0·76 feet. It is plain that the staff will then have been raised 4·44 feet (since $5{\cdot}2 - 0{\cdot}76 = 4{\cdot}44$),

and that its lower end will then be at a height of $95{\cdot}56+4{\cdot}44 \doteqdot 100$ feet. The man at the instrument beckons to the assistant with the staff to move until such a position is obtained exactly. This point fixed is on the 100 feet contour; it is marked on the map. It is now a simple matter to follow on round, keeping at the same height, to fix other points on the contour. The level itself is moved when the staff is too far off to allow a reading to be taken easily, the staff being kept fixed for the purpose, and the reading being taken again when the instrument is in the new position. Usually it is wise to finish on a bench mark, to see what error—if any—has been made. The 200 feet and other contours are obtained in the same manner.

Contours determined in this way are called **instrumental contours,** as distinguished from the "sketched contours" seen on the older maps.

Contoured diagrams.—What are known as contoured diagrams may be used to show graphically the distribution, not only of

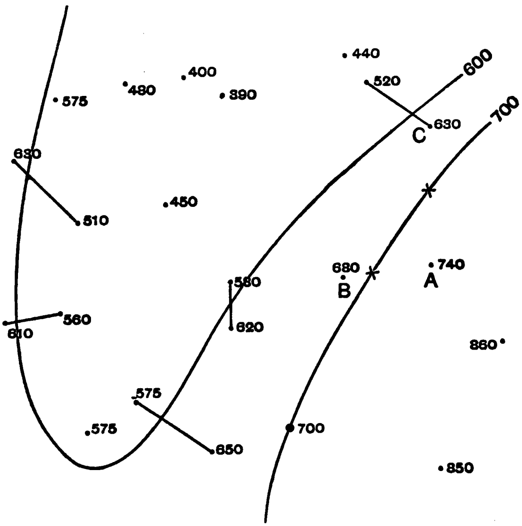


Fig. 20.—Method of drawing contoured diagrams. For explanation, see text.

relative heights, but also of temperatures (Chapter XII.), atmospheric pressures (Chapter XIV.) and other magnitudes. The general method of construction will be understood easily from an example (Fig. 20). In this map one point having a height of 700 ft.

is given; two other points (marked by crosses) of the same height are obtained thus. Join A and B; the difference between their heights is 60 feet. On the line AB a point 20 feet higher than B is required. On the assumption that the slope along AB is uniform, the required point is clearly $\frac{20}{60}$ or $\frac{1}{3}$ of the distance from B. Similarly, on the line AC, a point about $\frac{4}{7}$ of AC from A has a height of 700 feet. A smooth line, drawn through the three points, is the 700 feet contour line.

The V-shaped 600 feet contour line has also been drawn, through points obtained by dividing proportionally the cross lines shown. At the angle of the V, guidance is obtained from the two points marked 575, which are on a contour presumably parallel, or nearly so, with the 600 feet line. The contours of 400, 500, and 800 feet may be drawn in a similar manner from the heights given.

5. THE PRACTICAL USE OF MAPS.

1. **Symbols used in Ordnance maps.**—Study the symbols shown on p. 31, and, with their help, from the one-inch map of the Llangollen district (p. 33), make a list of all village post-offices, letter boxes and telegraph offices shown. Classify the various roads shown, according as they are footpaths, unmetalled and unfenced, unmetalled and fenced, metalled and unfenced, and metalled and fenced: stating in each case the length of the road in miles and what points it connects. Make a list of all level-crossings and of bridges over and under the railway respectively. Which of the places of worship shown have spires, which towers, and which neither?

2. **Coloured contour zones.**—Copy Fig. 24,* and colour the zones between successive contour lines differently according to height: employing various shades of dark green, light green, yellow, and from light brown to dark brown for successively greater heights.

3. **Sections along straight lines.**—(*a*) Rule a fine pencil line through D at right angles to EF on Fig. 24. In the manner shown at the foot of Fig. 24, draw a section along the line. Can the point G be seen from the point E? Can the highest point on the map be seen from E?

(*b*) If your atlas contains an orographical map (p. 36) of the south-eastern counties of England, draw, in the same way, a section along a straight line from Gravesend to Eastbourne. What is the least vertical scale which, in your opinion, shows the general configuration of the land satisfactorily? How many times is this greater than the horizontal scale?

* This map was set (Ques. 26, p. 41) in the Oxford Local Examinations, 1904.

(*c*) On the contoured map of Llangollen (p. 33) draw a fine straight line from the Post Office at Llantysilio to the summit of Castell Dinas Bran. Use a vertical scale of 1/10 inch to 100 feet, and draw a section along the line. Find out, from the section, whether the summit of the mountain is visible on a clear day from the Post Office. If not, how high would a captive balloon need to rise vertically above the Post Office to give, to an observer in it, a sight of the summit?

4. Road-book sections.—With a pair of dividers, open so that the points are $\frac{1}{4}$ inch apart, "step" from end to end of the road crossing Fig. 15. What is the length thus measured? Why is the real length probably a little greater than this? Could a more accurate result be obtained with the points $\frac{1}{8}$ inch apart? Set out the length of the road on a horizontal straight line, on a scale of 1 inch to 1 mile, and on it mark each point of which the height is shown by the contours on the map. At each of these points erect a vertical line, using a scale of heights $\frac{1}{10}$ inch = 100 feet, and join the upper ends of the verticals. Why is the Trough of Bowland referred to as a "saddle" on p. 24?

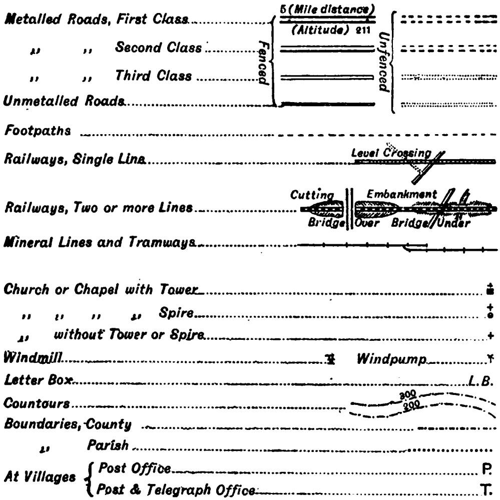


FIG. 21.—Conventions used in the one-inch Ordnance maps.

Conventions used in Ordnance maps.—An Ordnance map is much more than an attempt to portray a tract of country as it

might be seen from a balloon passing overhead. By means of a number of ingeniously devised symbols, the map conveys a great deal of information concerning features which would be indistinguishable in the best photographs that could possibly be taken from above on the same scale. Fig. 21 shows some of the symbols employed on Ordnance maps on the scale of one inch to a mile; many others are in use on maps on the larger scale of six inches to the mile.

The use of Ordnance maps may be illustrated by the following account of some of the more obvious facts shown in a fairly complicated map—that of the Llangollen district on p. 33. The River Dee here flows from west to east, falling from a height of 400 feet on the west to 294 feet by Llangollen railway station. Being shown with two lines, it is more than 15 feet in width. For part of its course it acts as the county boundary between Merioneth and Denbigh, and in another part as the boundary between two parishes. In the area shown the Dee makes several distinct bends. At the Horseshoe Falls at Llantysilio it supplies the Shropshire Union Canal, which for some distance runs parallel with it. In general the land rises steeply on both sides of the river, but on the left of the map, and again where the most distinct loop is made, at least one bank is more or less level for a width of about one-third of a mile.

The Llangollen and Corwen section of the Great Western Railway (a single line to a point one mile from Llangollen station) obtains easy gradients by keeping close to the right bank of the Dee, except where the river makes its greatest curve. This the railway avoids by a tunnel which, though less than 700 yards long, shortens the distance by about two miles. The main highway from Corwen to Llangollen—a fenced and metalled road of the first class—though also following the river valley in a general sense, makes fewer concessions to gradient, and has a straighter course than the railway. At Glyn-Dyfrdwy the road leaves the river and railway, and takes the opposite side of a hill in order to cut off a curve. Again the three run side by side, soon to turn sharply to the left to avoid a ridge which juts out across their path. The river winds round the end of the ridge; the road—being on a higher level—takes advantage of a dip in the middle of the ridge, and so is able to cross it with a much smaller detour than is made by the river; while the railway reaches the other side by the tunnel.

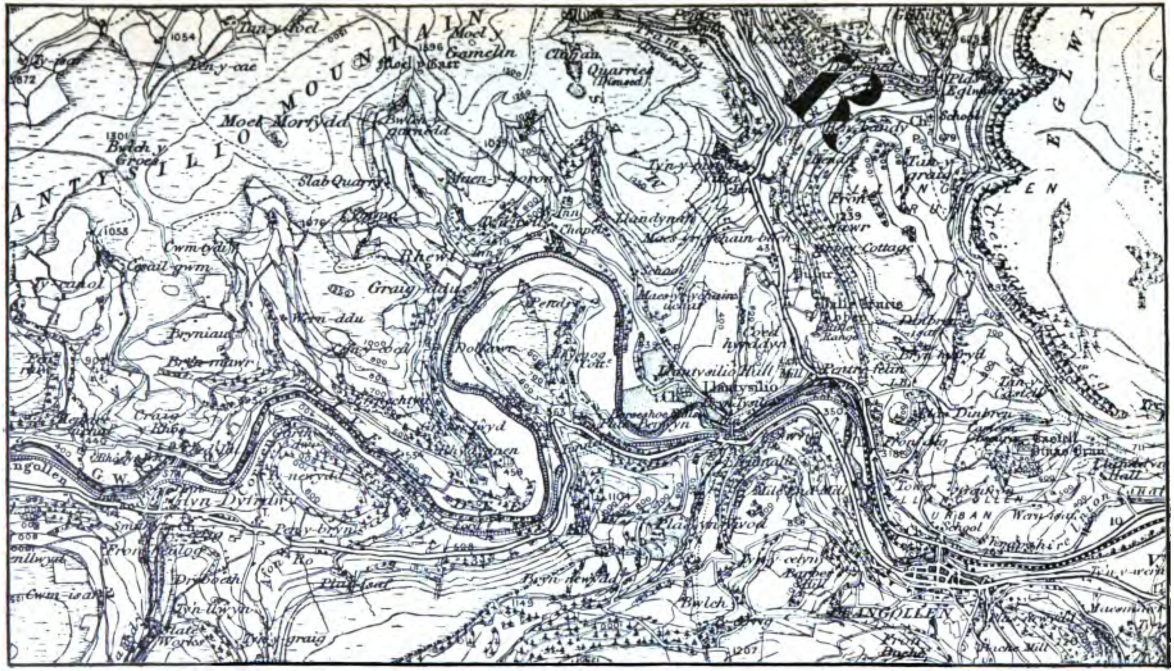


FIG. 22.—A portion of Sheet 121 of the Ordnance Survey one-inch map. Scale, 1 in. = 1 mile.
(Students are recommended to procure the hachured *coloured* edition of this map.)

Though the main road thus crosses the ridge, another continues the route parallel to the river round the end of the ridge. This road is for the first half mile both unmetalled and unfenced, but is thereafter fenced on the left or river side until Rhysgog Cottage is reached. It is unfenced for the next quarter of a mile, and is then fenced on both sides between Plas Berwyn and Llantysilio.

It is unnecessary to describe in similar detail the other roads and footpaths shown on the map. It will be noticed, however, that they have a marked tendency to follow river valleys or contour lines. The heights above sea level of dotted points on

Photo. Frith & Co

FIG. 23.—Llangollen from Barber's Hill. (Compare with Fig. 22.)

the roads are marked in feet; the distances in miles from Llangollen are indicated by larger numbers, usually at mile intervals. Thus, the map shows that on the Glyn-Dyfrdwy road the height is 294 feet at Llangollen, 300 feet about 1 mile, 350 feet at $1\frac{1}{4}$ miles, 400 feet about $1\frac{7}{8}$ miles, 563 feet at $2\frac{3}{4}$ miles, 508 feet at $3\frac{3}{4}$ miles, 600 feet at $4\frac{3}{4}$ miles, and 500 feet at about $5\frac{1}{2}$ miles from Llangollen,—facts which may be indicated in another way in the manner shown in Fig. 25.

Antiquities (*e.g.* Valle Crucis Abbey and Castell Dinas Bran) are distinguished by special type; thus the type in these cases is Old English, showing that the antiquities are not Roman though constructed prior to 1066. Small triangles indicate points

the positions and heights of which were determined by trigonometry. The shading on the map shows the ground in different parts as bare of vegetation, covered with woods, fir plantations, or with rough pasture; parks and ornamental grounds are stippled. Churches and chapels are variously marked as with towers, with spires, or without either.

The student should make a practice, when examining a contour map, of forming as clear a mental picture as possible of the configuration of the ground; and at every opportunity he should compare the map with the actual landscape or with photographs. Without difficulty he will identify, for example, on the Llangollen map the chief features shown in Fig. 23: the conical hill of Castell Dinas Bran on the left, the Eglwyseg Rocks in the background, the River Dee in the foreground, and the railway and the town and bridge of Llangollen in the middle distance.

Contours only appear on the Ordnance maps of the scales of 6 inches, 1 inch, and ½ inch to the mile respectively. They begin, as a rule, at the 50 feet line above the assumed mean sea level at Liverpool * (p. 27), and are shown at 50 and 100 feet, and then at intervals of 100 feet up to 1000 feet above mean sea level. Above that height 250-feet contours are generally used. Maps on scales of 1 inch or less to a mile may also be had, with the hills shaded by hachures or otherwise; while on maps on scales of 6 inches or more to the mile, surface levels are shown in feet at various points along the roads.

It is plain that by an attentive study of Ordnance maps alone a very thorough knowledge of a district may be obtained. Not only may the suitability of the roads for driving, cycling or walking be gauged, and a fair idea gained of the character of the scenery as viewed from various points and in various directions, but useful information regarding the positions of post and telegraph offices, inns, churches, smithies, interesting antiquities, and so forth may also be gleaned. It is even possible, as has been found in Ex. 3, (*a*) and (*c*), Sec. **5**, to learn from an Ordnance map whether from a certain point any particular feature of the landscape is visible.†

* Often referred to as O.D. (Ordnance Datum line). See Question 6, p. 39.

† For further information on Ordnance maps, the student is recommended to obtain the official *Ordnance Survey Maps of the United Kingdom: a Description of their Scales, Characteristics, etc.* (Stanford) 6d., and to study the beautiful examples of maps on various scales which it contains.

Maps representing height by colour.—With the object of rendering variations in height more conspicuous, many maps—based on Ordnance maps—are now published in which all ground between certain contours is coloured according to a definite scale of tints. Admirable examples of such **orographical maps** are now available at a moderate price, and they are also to be seen in most standard atlases and in the best guide-books. Orographical maps

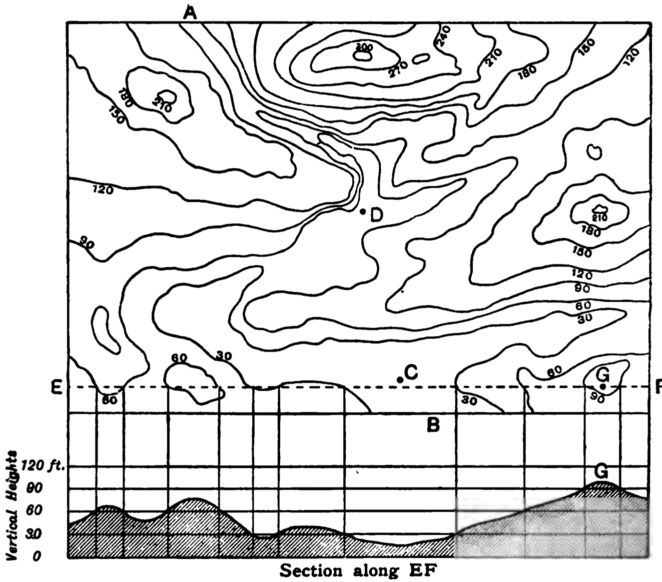


FIG. 24.—Method of drawing a section across a contoured map.

are often in colours varying from dark green to yellow, in order of height, for land up to 1000 feet; and from light brown to dark brown for increasingly greater altitudes. A greater range of tints is naturally used when it is desired to indicate contours at smaller intervals on a large scale map. In a similar manner the varying depth of the sea below its mean level is often marked by contours and emphasised by conventional shades of blue. Maps in which both the depth of the sea and the height of the land are indicated are known as **bathy-orographical maps** (Fig. 75).

Sections.—One of the advantages of contoured maps is the ease with which sections may be drawn from them in order to show more clearly the varying slope of the ground in any definite direction or along any particular route. Such sections are especially helpful to tourists.

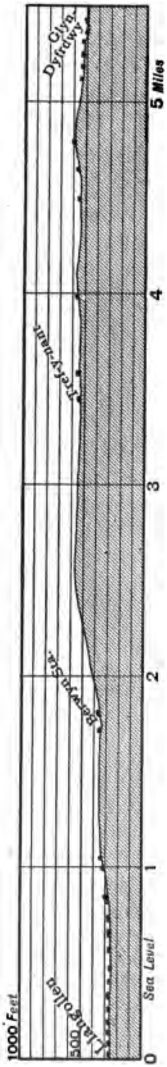


FIG. 25.—Road-book section from Llangollen to Glyn-Dyfrdwy. (Compare with Fig. 22.)

The method of drawing a **section along a straight line** (EF) will be obvious from a study of Fig. 24. The vertical scale of the section is usually made much greater than the horizontal, in order to emphasise variations of gradient, which, without exaggeration, would often be scarcely appreciable. When the country represented is fairly flat, the vertical scale used is naturally greater than in the case of a hilly district. For most purposes the vertical scale is sufficiently large if it allows a difference of 1 inch between the heights of the highest and lowest points in the section, but modifications will naturally be made to suit special conditions. In any case it is best to rule a horizontal line to represent each height distinguished by a contour on the map, in the manner shown in Fig. 24. A vertical line is then dropped, to cut these, from each point where the line of section crosses a contour on the map. In joining up the surface points thus obtained, to give the required line of surface, special care is necessary where the line of section crosses the same contour repeatedly.

Exactly the same method is followed in drawing a section across a country or continent from an ordinary orographical map. In this case the contours are represented by the lines separating differently coloured areas on the map.

Very erroneous impressions of the nature of the surface will be gained from the use of

such sections unless the exaggeration of the vertical scale be borne in mind.

It may be desirable sometimes to know whether one point shown on a contoured map is visible from another; whether, for example, the point *G* in Fig. 24 would be visible from the point *E*. A section (the scale is immaterial) along a *straight* line connecting the two points at once solves the question.

Sections along winding lines.—In **road-book sections** (Fig. 25) prepared for cyclists and pedestrians, the route, however it may wind about in reality (Fig. 22), is shown as if it lay along a straight line of the same length, and a vertical scale is chosen which renders obvious all important changes of gradient. The same method is often employed (p. 137) to show the changes in slope along the course of a river; such a diagram is called a **river profile.**

EXERCISES ON CHAPTER II.

1. What is a contour line? What are contour lines used for? Can you learn anything as to gradient from them? Give examples. (L.C.C.)

2. For a distance of 5 miles a coast line consists of precipitous cliffs 200 feet high, broken here and there by the mouths of small rivers. From the edge of the cliff the ground rises fairly uniformly, and culminates 3 miles inland in a range of hills about 600 feet high. Represent such a district by means of contour lines 100 feet apart. (Prel. Cert.)

3. If you were given a contoured map on which the summits of two hills are marked *A* and *B*, and were asked to draw a section along the straight line joining *AB*, how would you set about it? What is the use of a section of this kind?

4. A gently-sloping region terminates upwards in a broken ridge, the peaks of which rise to heights of over 2000 feet above sea level. The region is drained by the upland tributaries of a great river. By means of contour lines represent such a region. (Prel. Cert.)

5. Explain what is meant by contour lines.
A lake lies 1000 feet above sea level, and is surrounded by high lands rising steeply from its shores to a height of 1300 feet above sea level, but sloping gradually on all sides down to the sea 50 miles off. Draw a sketch map, and show this by means of contour lines. (C.P.)

6. A stream, flowing along a steep-sided valley in a hilly district, is dammed for a reservoir just below a point where several feeders

join the main stream. When filled, the level of the water in the reservoir stands at 400 feet O.D. Draw a map of the district and reservoir, using contour lines. (Prel. Cert.)

7. A village is situated at the crossing of two straight roads, one of which runs due N.-S. 100 yards up the road to the N. stands the church, and at half that distance down the S. road stands the village post office. Between the two S.-trending roads is the village green; its S. boundary, 60 yards long, begins by the post office and runs at right angles to the road on which the post office stands. 40 yards beyond the village green on the road, which runs roughly south-west, where the railway crosses the road at right angles by a bridge, is the railway station. Draw a map of the village to a scale of 20 yards to one inch, using Ordnance Survey symbols. (Cert.)

8. *A* and *B* are two church spires 5000 feet apart, *B* lying due east of *A*. From a third point *C* it is observed that *A* lies exactly north-west, and *B* north-north-east. Draw a rough plan, showing approximately the relative positions of *A*, *B* and *C*; and explain how, with the aid of a graduated rule and of a protractor measuring angles, you would proceed to draw a plan accurately to scale. (C.S.)

9. How can you represent on a map (*a*) the distance from one point to another, (*b*) the area of a region, (*c*) the elevation of the land? Draw a sketch map of any region you know, to illustrate your answer.

10. The surveys from which maps are drawn usually depend chiefly on "triangulation from a base line." Explain shortly what is meant by this. (C.S.)

11. Show how the height of a hill may be determined by the use of a barometer. (C.S.)

12. Draw a sketch showing a piece of main road which crosses a meadow (road unfenced on both sides), then passes over a stream by means of a bridge, next goes through a wood (where both sides are fenced), and on coming out of the wood passes under a railway bridge. The railway crosses the road at right angles, on an embankment.

N.B.—Use the conventional signs employed in the maps of the Ordnance Survey. (O.J.)

13. In cycling through the village of *X*, I ask my way to the village of *Y*. I get the following directions:

"Go down the village street for about a quarter of a mile till you come to the church, which is on your left hand; turn sharp to the right, cross the bridge over the railway; turn to the left, and then follow the road running alongside the railway for two miles till you come to four cross-roads, in a wood, just after crossing a bridge over a stream. Turn to the right, and keep to the road beside the stream for a mile; you will see the village of *Y* close by on your right."

Draw a rough sketch map which would help me to remember these directions. (O.P.)

14. Suppose you are going to walk to a railway station ten miles away across a stretch of open country where there are no roads or fences. You have a compass and an Ordnance map of the district, on which you can recognise the point from which you start.

Describe how you would use the map to find your way. (O.P.)

15. Two places are connected by a road; the distance is a mile and a quarter, and their heights above sea level are 106 and 206 ft. respectively. What is the average gradient between them? (C.J.)

16. Draw a map to show the hills, plains, rivers, chief towns and villages, and the most important railways within ten miles or so of your school. (L.J.S.)

17. What do you understand by a contour?

Draw a contoured sketch map of two mountain peaks with a valley between them.

18. Draw a contour map of an imaginary island. Let the highest point, 1500 feet, be somewhere near the centre. Fill in imaginary contour lines at 100, 400, 700, 1000 and 1200 feet. Let the steepest part be on the west.

19. Describe briefly how maps are made, giving special attention to methods of marking elevation above sea level. (N.F.U.)

20. Explain the use of contour lines on a map.

Draw a contoured map of a ridge 2 miles long and $\frac{1}{2}$ mile broad, running east and west. The top of the hill is a plateau 400 feet high, 1 mile long and $\frac{1}{8}$th mile across, and the descent is steeper on the south side than on the north. Draw the map to a scale of 2 inches to the mile, and show contour lines for every 100 feet.

21. Using the signs employed in the maps of the Ordnance Survey, make a sketch showing a forest composed of coniferous and deciduous trees, through which passes a footpath. On emerging from the forest the footpath crosses a river (which bounds the forest on the north and east sides) by means of a stone bridge. It then crosses a narrow meadow and joins a metalled road which at this point is running in a north-westerly direction, having previously a westerly direction: standing at this angle in the roadway is a church with a spire, while to the north of the roadway is a marsh. Some distance to the west of the church the road crosses a railway at a level-crossing, the railway being at right angles to the direction of the road.

22. Draw a contour map of an imaginary island with a peak 5000 feet high near the centre. Show a steep slope to the west and a gentle slope to the east. Show a river with two tributaries.

23. Draw a map of a volcano about 5000 feet high, and 9 miles in diameter at the base, with a crater a quarter of a mile in diameter. Use contour lines at 1000 feet intervals and a horizontal scale of 3 miles to an inch. Make a vertical section with the same horizontal scale and a vertical scale about three times as great. (C.S.C.)

24. Describe briefly how you would measure: (1) the length of a level road; (2) the slope of a road. (C.S.C.)

25. Represent the following on a map, using contour lines for the hills:—A valley running more or less North and South, with hills on the West rising to 800 feet and on the East to 600 feet. A stream flows along the valley, entering at a height of 500 feet and leaving at 200 feet. There is a small side valley on the East, partly filled by a mountain lake. There is also a railway in the lower half of the valley, with a walled-in road, which is an open moor road in the upper half of the valley. (C.P.)

26. On the accompanying map (Fig. 24) the configuration of the ground is shown by contour lines at vertical intervals of 30 feet. A stream runs from *A* to *B* and is joined by tributaries at *C* and *D*. Show by thick lines the probable courses of the stream and its tributaries, and draw a vertical section of the country from *E* to *F* in the space provided below the map. (O.S.)

CHAPTER III.

MAP PROJECTION.

6. LATITUDE AND LONGITUDE.

1. A point on a sphere.—Obtain a number of balls (spheres) of various sizes, such as a marble, a billiard or ping-pong ball and a tennis ball. Select one if possible with no marks on its surface and make a dot on it. If you were asked to mark a second plain sphere with a dot in an exactly similar position, would you consider the request reasonable? If not, why not?

2. The axis and poles of a sphere.—Select an orange approaching the spherical shape as nearly as possible. Notice the scar where the stalk of the fruit was fixed, and exactly opposite, on the other side of the orange, a dot. Stick a darning needle through the orange, so that it passes through both these points, which may be called the *poles*. Make the orange rotate by twirling the needle between finger and thumb. Mark the surface in various places by attaching small pieces of gummed paper, and rotate again. What kind of curve is marked out by the motion of each bit of paper? Which piece of paper moves over the greatest path during one rotation? During one second of time? Which moves over the least? Which piece rotates most quickly? Which most slowly? Are there any points on the surface of the fruit which do not rotate at all?

Take out the needle and reinsert it at one pole, but push it through the orange in a different direction, so that it comes out a little distance from the other pole. Twirl the needle again; what difference do you observe in the rotation of the orange?

3. Great and small circles.—Roll a lump of plasticine between two boards until it is as nearly spherical as you can make it. Cut out of stiff cardboard a circular hole just, but only just, large enough for the sphere to pass through. Divide the edge of the circular hole, that is, the circumference of the circle, into 12 equal parts, and mark the

points as in Fig. 26. Push a needle carefully through the centre of the sphere and lay the sphere in the hole so that the projecting ends of the needle both rest on the same side of the card, at the points marked 90°. Neglecting the thickness of the needle and card, what fraction of the sphere is on each side of the card? What name is given to half a sphere? Hold the sphere still, and mark a line on its surface by running a pencil point gently along the edge of the hole in the card.

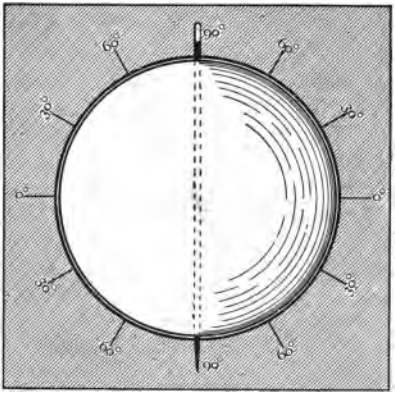


Fig. 26.—To illustrate Expt. 3, Section 6.

What is the shape of the line? A circle drawn on the surface of a sphere and dividing it into hemispheres is called a *great circle.*

Place the pencil point at one of the points marked 0° on the card and, keeping the poles at 90°, rotate the sphere once in the hole so as to mark a circle on its surface half-way between the poles.

It is called the *equator.*

Is the equator a great circle? In the same way, trace circles on the sphere parallel to the equator, through the points marked 30° and 60° on the card. Are these also great circles?

These circles are called *parallels of latitude.*

Lift the sphere and replace it in the hole so that the equator lies in the plane of the graduated card, with the first circle (marked as described above) intersecting it at 0°. The needle will then be perpendicular to the plane of the card. Mark also on the equator the positions of the other points shown on the card. Replace the sphere in the hole in its first position, and run the pencil point around the edge of the hole to draw great circles through the marked points crossing the equator. Notice that all these, like the first circle drawn, pass through the poles.

Great circles passing through the poles of a sphere are called *meridians.*

How many meridians could be drawn on the same sphere? Take out the model and study the network of lines on its surface. Preserve it for use in Expt. 5 (*c*), Sec. **8**.

Given a sphere on which the poles and one meridian were already marked, could you now devise a method of stating exactly the position of any dot on its surface?

4. The graduation of the circle.—Examine a semicircular protractor and compare its method of graduation with that of the equator on a terrestrial globe. Find on the globe the meridian passing through London (Greenwich) and notice that its intersection with the equator is the zero point on the latter.

The *longitude* of any place is specified by the point at which the meridian of the place cuts the equator.

Also notice how *latitude—i.e.* the angular distance north or south of the equator—is expressed on the terrestrial globe.

5. Examples in latitude and longitude.—Find on the terrestrial globe what occupies each of the following approximate positions: (*a*) lat. 53° N., long. 13° E.; (*b*) lat. 22° N., long. 88° E.; (*c*) lat. 16° S., long. 6° W.; (*d*) lat. 22° N., long. 114° E.; (*e*) lat. 35° S., long. 58° W.

6. Antipodes.—Write down the latitude and longitude of the antipodes of the above positions (*i.e.* the points on the other side of the globe at which straight lines passing through them and the centre would cut the surface).

Preliminary considerations.—The earth is so nearly spherical that for our present purpose we may ignore any departures from this shape which it presents, although this question must be referred to again in later chapters. Now, a little thought will show that in any attempt to specify the position of a given point on a sphere (for example the position of a certain town on the surface of the earth), the perfection of symmetry of the globe is in itself a source of difficulty, for, in order to describe position, we must plainly have some well defined points to which distances and directions may be referred. On the surface of a sphere in general there is no point which is distinguished inherently from other points.

Our earth, however, is not at rest; besides having other motions, it is constantly spinning, or rotating, in a very regular manner, somewhat as a small sphere of cork or plasticine might be made to rotate if a needle were thrust through its centre to represent the **axis** and then twirled between finger and thumb. On the surface of such a spinning globe two points called the **poles** —the two points at which the axis comes to the surface—take no

part in the spinning motion; while all other points on the surface rotate in circles of size depending on their distance from the poles. The greatest of such circles is that described by any point half way between the two poles.

The poles of a spinning globe—thus distinguished from all other points on its surface by being at rest—may evidently be used as the points of reference we are seeking. Their employment in this manner for geographical purposes immediately becomes clear on examination of a model globe representing the earth.

Latitude and longitude.—Such a "terrestrial globe" is covered with a network of numbered reference lines consisting of two sets of circles (Fig. 27). All the circles of one set—called **meridians** or

FIG. 27.—Parallels of latitude and meridians of longitude, separate and combined.

lines of longitude—pass through both poles, and the centre of each is the centre of the sphere itself. They are evidently as large as any circles drawn on the surface of the sphere can possibly be. For this reason the meridians are called **great circles.**

Of the other set of circles—known as the **parallels of latitude**—only one is a great circle. This is called the **equator**; it passes round the globe half way between the two poles, and consequently bisects each meridian. The remaining lines of latitude are "small" circles parallel to the equator; they are shown at equal intervals between the equator and the poles. Their centres lie on the axis of the sphere at intervals between the centre of the sphere and the poles.

The numbering of the lines depends on the familiar method of referring to an arc of a circle in terms of the angle subtended by the arc at the centre of the circle. For example, $\frac{1}{360}$ part of the circumference of a circle is referred to commonly as *one degree*

of arc, because it subtends an angle of one degree (1°) at the centre. On the same principle, $\frac{1}{4}$ of the circumference of a circle is referred to as 90° of arc, $\frac{1}{2}$ as 180°, and so forth. Similarly, $\frac{1}{60}$ of a degree of arc may be called 1 *minute* (1′) of arc, and $\frac{1}{60}$ of a minute 1 *second* (1″) of arc.

The great circle called the equator is graduated in this manner, the zero point most commonly used being the point at which the meridian passing through Greenwich—called the **prime meridian** —cuts the equator. Any other meridian is distinguished by the angular distance between the zero point and the point—east or west of it—where the meridian in question cuts the equator. Thus, the meridian 20° west of Greenwich is that meridian which cuts the equator 20° of arc to the west of the zero point, and all points on it are said to have a longitude of 20° W. It is obvious that the meridian 180° W. is also 180° E., and that this and the prime meridian are halves of the same great circle.

Any meridian may be taken as zero instead of that of Greenwich, but when no zero is specified that of Greenwich is understood.

The arc of a meridian between the equator and a pole is one-quarter of a great circle, and is graduated into 90° (*i.e.* $\frac{360°}{4}$) from the equator, northward or southward as the case may be. Thus, a place is described as of latitude 30° south, if it lies on a line of latitude (parallel to the equator) which cuts the meridian of the place at a point 30° to the south of the equator—*i.e.* $\frac{1}{3}$ of the distance, measured along the meridian, from the equator to the south pole. The latitude of the equator is 0°; that of each pole is 90°.

Antipodes.—Points are said to be antipodal to each other when they are at opposite ends of a straight line passing through the centre of the earth. Obviously one is as much north as the other is south of the equator, and lies on a meridian which is 180° of arc from the longitude of the other. Thus a point of lat. 50° N., long. 3° W., and one of lat. 50° S., long. 177° E., are the antipodes of each other.

It should be clear that when the latitude and longitude of any place are both known, the position of that place can be marked on a globe accurately. In Chapter IV., methods will be explained by which explorers or sailors are able to

determine the latitude and longitude of their positions. Given the positions of a sufficiently large number of places, as determined by the observations of explorers, it is therefore possible to draw the map of any country, or even of the world, *on a globe.*

7. THE PRINCIPLES OF PROJECTION.

1. Cut out small squares of tracing-paper, say of 1 in., ¾ in., ½ in. and ¼ in. side respectively, and apply then in turn to the surfaces of terrestrial globes of different sizes. Notice (*a*) that although the paper is flexible, only a very small piece can without creasing be in such entire contact with the globe as would be necessary for accurate tracing; (*b*) that the smallest piece needs the least creasing to ensure contact; (*c*) that the same piece of paper is creased less on a large globe than on a small one.

2. Take a small hollow india-rubber ball, cut out a small piece having four equal sides, and then stretch out the piece on a flat sheet of paper. Run the point of a pencil round the edge and then allow the piece to resume its former shape. Compare the pencil outline with this shape.

3. The orthographic projection.—(*a*) If possible, construct or obtain a globular wire cage, about 9 in. in diameter, the wires representing respectively meridians 30° apart, the equator, and the parallels of latitude 30° and 60° N. and S. The construction will be understood easily on examination of a wire gas-flame protector.* Hold the cage in the sunlight, and observe and draw the shadow cast on a screen behind it, (i) when the shadow of one pole exactly overlies the shadow of the other, and the axis is perpendicular to the screen; (ii) when the screen is as before but the axis is parallel to it.

(*b*) Copy Fig. 28 on twice the scale, drawing by freehand the elliptical curves representing meridians. How many times greater is *Oc* than *ba*? Place transparent squared paper over your drawing, and compare the areas of the meshes *H*, *K* and *L*, which of course represent equal areas of the globe-surface.

(*c*) Draw an "*equal area*" *modification of the orthographic projection* by making *OP* and *PQ* each one-third of the distance from *O* to the pole, and *ab*, *bc* and *cO* each one-third of *aO*; and satisfy yourself, by using transparent squared paper, that areas are correctly represented on it.

*The accurate apparatus devised by Prof. A. J. Herbertson (and sold by Messrs. George Philip and Son, Ltd., 32 Fleet St., London, at 21s.) may be used with great advantage.

Difficulties to be overcome in map-drawing.—The advantages of being able to represent any part of the earth's surface, not on globes only, but also on plane (*i.e.* flat) sheets, are so great that geographers have given special attention to the best means of doing it. Perhaps the method which would most naturally suggest itself is that of transferring outlines directly from the globe to the plane surface by tracing, or by some "printing" process. Except for very small areas, however, this is impracticable, for it is impossible without distortion to spread out on a plane surface any part of a spherical surface, even if it is elastic. It is equally impossible to make a plane surface—say a sheet of paper—fit quite accurately on any part of a spherical surface.

Although some amount of distortion, either of shape or size, is thus inevitable in any attempt to represent a portion of a spherical surface on a plane, it is nevertheless fairly easy to draw a map on which one selected feature at least shall be accurately shown, although other features are of necessity incorrect. In maps of the world on Mercator's projection, for example, the *shapes* of the countries are drawn correctly; on the other hand, the *scale* varies enormously in different parts of the map, so that an entirely misleading impression of the relative *areas* of different countries is conveyed to anyone studying the map without knowing the principles on which it is drawn. Conversely, maps of the world drawn by other methods may display all areas to a correct scale while at the same time they show countries seriously distorted in shape. In general, it may be said that all plane maps of large sections of the globe are inaccurate in some one respect at least.

The smaller the area to be represented, however, the less pronounced is the curvature of the earth, and consequently the easier it is to approach entire accuracy. Indeed, "the whole of Europe south of the latitude of Edinburgh can be plotted with a maximum linear error of 1 per cent."; * while in the one-millionth Ordnance map of the United Kingdom, which extends from lat. 50° N. (*i.e.* south of Land's End) to lat. 61° N. (north of the Shetland Isles), the maximum linear scale error amounts to 1 in 433 only, and the greatest local error is the same.

Map-projection.—It is obvious that what is required is really a

* Lt.-Colonel Close.

representation, on a plane surface, of the network of lines of latitude and longitude with which the terrestrial globe is covered. When this has been obtained, the filling in of the details of the map is a relatively easy matter. Such a representation is best called a **map-network**. It is more commonly known as a **map-projection**, because some of the simpler networks in use are obtained by geometrical methods of projection. To understand the process, let us suppose that we have a globular cage made of wires which occupy the positions of certain of the lines of latitude and longitude. The shadow of the wires, cast upon a flat screen by a light, is, in the strict geometrical sense, a projection of the cage. It is, however, clear that the shadow will differ in appearance according to the position of (1) the light, (2) the screen.

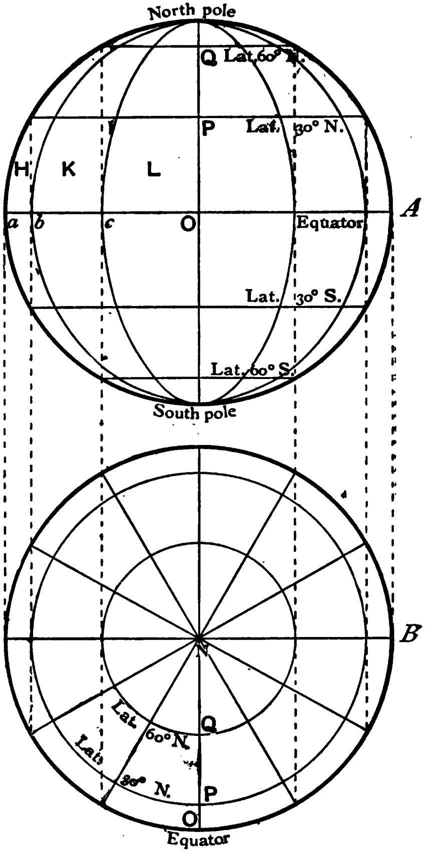


FIG. 28.—Orthographic projection.

Orthographic projection.—If the source of illumination is at an infinite distance (as would practically be the case if sunlight were employed), so that the light rays are all parallel, and the screen is a plane at right angles to the direction of the light, the shadow forms a map-network known as an **orthographic projection**.

If the wire skeleton earth be turned so that its north pole is directed towards the sun, with its axis parallel to the direction of

the light, the shadow formed on the screen will be like Fig. 28, B. If, on the other hand, the model be so placed that its axis is at right angles to the direction of the light rays, the shadow on the screen will have the appearance of Fig. 28, A. The two diagrams, so drawn, may be said to be projected from each other; they represent the same model as seen from two different directions, which are at right angles to each other.

The diagrams show clearly that parts approaching the edge are represented on an increasingly smaller scale; so that, on Fig. 28, A *Oc* is greater than *cb*, and *cb* greater than *ba*, although the actual distances they represent are in fact equal; and the unequal meshes *H*, *K* and *L* on the map represent equal areas on the globe. Again, in Fig. 28, B, *NQ* is greater than *QP*, and *QP* greater than *PO*, though these three lines also represent equal distances.

In the orthographic projection of a hemisphere as seen from the "side" (*i.e.* in a direction at right angles to the axis) the parallels of latitude are straight lines, while the meridians are for the most part ellipses (Fig. 28, A). In the orthographic projection of the polar regions (Fig. 28, B) the parallels of latitude are concentric circles, and the meridians are radiating straight lines.

It is clear that a true orthographic projection such as has been described would be practically useless except for regions falling very near the centre of the map. It is sometimes used for maps of the polar regions.

Modifications of the orthographic projection.—A modification of the orthographic projection, in which all the distances along meridians are true to scale, could be constructed easily. Measurements along parallels of latitude, however, would in this case be inaccurate, and consequently areas would not be proportional.

On the other hand, a "projection" in which the equator also is divided into equal parts, and ellipses (drawn through the points of section and the poles) represent the meridians, does display **areas to the same scale** throughout, although the shapes of countries near the edge of the map are necessarily distorted.

The orthographic projection and its modifications have been discussed at greater length than their intrinsic merits warrant, because they serve very well as an introduction to methods of obtaining the far more useful map-networks which must be considered next.

8. THE PRINCIPAL METHODS OF MAP-PROJECTION.

1. The gnomonic or central projection.—(*a*) In a darkened room place the skeleton globe against a wall, with its axis parallel to

the wall. Hold the flame of a lighted taper (or, better, a small movable gas-flame) as near the centre of the model as possible, and observe the appearance of the shadows of the meridians and parallels respectively.

(*b*) Hold the model against the wall with its axis perpendicular to the wall, and repeat the experiment.

(*c*) Copy Fig. 29 to twice the scale.

2. The stereographic projection.—(*a*) Place your eye close to the equator of the wire model, and observe and describe the appearance of the meridians and parallels respectively of the opposite hemisphere.

(*b*) Taking one pole as the point of projection, project on paper the map-network of the opposite half of the globe. In what respect is this method superior to the gnomonic projection of the polar regions?

3. The equidistant or globular projection.—(*a*) Place the skeleton globe against the wall of a darkened room, with the axis parallel to the wall, and move a small flame backwards and forwards until you obtain the position at which the shadow seems least distorted. Measure the distance of the flame from the globe. What decimal of the radius of the globe is this distance? How does your result compare with 0·707, the value of $\frac{1}{\sqrt{2}}$?

4. Simple cylindrical projection.—(*a*) Obtain a piece of tracing-paper about 30 in. long and 6 in wide, and roll it up to from a short cylinder which will just fit over the equator of your wire globe. Whilst a friend holds a small flame carefully at the centre of the globe, study the shadow of the wires as it can be seen on the outside of the tracing-paper. If you could draw it on the paper and then unfold the cylinder, what kind of map-network would you have?

(*b*) Copy Figs. 32 and 33 on twice the scale.

5. Simple conical projection.—(*a*) Take a circular piece of paper, say 6 in. in diameter, and fold it up, as a filter paper is folded, to form a cone. Gum the folded parts together, so that the cone will preserve its shape. Smear a cricket ball evenly with soft coloured chalk, or with vaseline, and drop the paper cone gently on the ball. After a minute or two remove it without rubbing it about on the ball. Cut the cone open along a fold. What is the shape of the mark on it?

(*b*) Draw a circle of 2 in. radius and mark on its circumference the positions of latitudes 30°, 45° and 60°. Draw a pair of tangents at each latitude and measure the angle at which the tangents of each pair intersect.

(*c*) Take the plasticine model globe used in Expt. 3, Sec. 6, and place it gently in a glass funnel, with the needle along the centre line of the funnel-neck. Estimate the latitude at which the globe touches the glass. What is the approximate apical angle of the funnel?

(*d*) Make a conical cap of tracing-paper to fit over your wire globe. Cut off the apical part and then, having fitted the truncated cone on the globe to touch it along a parallel of latitude (real or imaginary), hold a small flame at the centre of the model in a darkened room and study the shadow of the wires on the tracing paper.

6. Transference of routes from globe to maps.—On a terrestrial globe stretch a piece of string along the shortest possible line between Freetown (Sierra Leone) and Petropavlovsk (Kamchatka), and mark the line by chalk. Is this line part of a great circle? Select ten points on the line at about equal distances, and observe the latitude and longitude of each. Mark them (or as many as are included) on maps of Africa, of Asia, of the World in Hemispheres, and on Mercator's projection. On each map join the points by a pencil line. In how many cases is the line straight? Similarly transfer from the globe to different maps the shortest course from London to Shanghai, from Yokohama to San Francisco, and from Wellington (New Zealand) to Valdivia (Chile) and compare their appearance in each case.

Principal map projections.—It has been seen that the great drawback of orthographic projection—in which the hemisphere is supposed to be seen by an eye placed at an infinite distance—is the distortion caused by the fact that the central region of the map is on a larger scale than that of the parts nearer the edge. It is natural to suppose that this fault could be rectified by imagining the eye much nearer, and to try the effect of projecting the hemisphere from points at various distances from it. In making such trials it is a help to the imagination to consider the plane of projection as a screen, and the map-network as the shadow of a skeleton hemisphere thrown on the screen by a light placed at the point of projection.

The gnomonic or central projection.—In this case the point of projection is the centre of the earth, while the plane of projection touches the earth but does not cut it. Fig. 29 shows the map-network when the plane touches the earth at the North Pole. It will be seen that from the pole to lat. 50° the distortion is not very pronounced, although it increases towards the edge of the projection; but the scale rapidly becomes grossly exaggerated as we pass to regions of "lower" latitudes than 50°. As in the polar

orthographic projection, the meridians are represented by radiating straight lines.

When the plane touches the earth at a point on the equator, the gnomonic projection represents all meridians as parallel

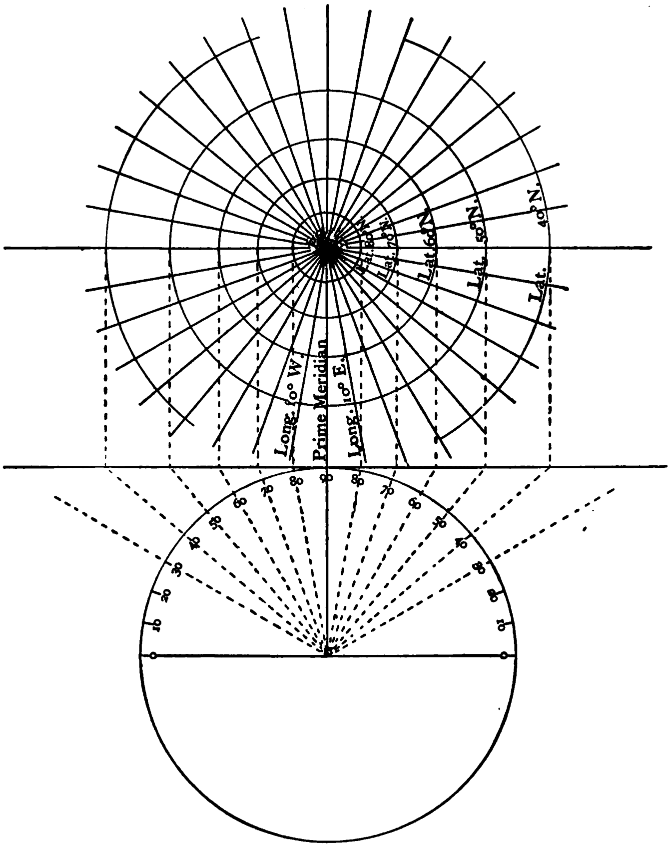


FIG. 29.—Gnomonic or central projection.

straight lines at right angles to the equator. Indeed, *all great circles are represented by straight lines* in this projection. The lines of latitude are more or less curved. For polar regions the gnomonic projection possesses advantages over the orthographic; it is largely used, however, by American navigators, for charts of

the oceans, since a straight line drawn between any two points on a gnomonic map represents an arc of the great circle passing through those places, and therefore shows the *shortest* (though not necessarily the best) route between them.

The stereographic projection.—In this method one hemisphere is projected on the tangent (touching) plane from the central point of the surface of the other hemisphere. Fig. 30 shows that, although the scale still increases as the edge of the map is approached, the disproportion is much smaller than in the gnomonic. Also, all parallels of latitude, as well as meridians, on the globe are projected as arcs of circles on the map, and are plotted, therefore, more easily. A further and important advantage possessed by the stereographic projection is that on the map all intersecting lines are shown cutting each other at the same angles as on the surface of the globe. As a result, perfect local accuracy of shape is obtained. Owing to this last-mentioned property, the stereographic is grouped with Mercator's (p. 57) as an **orthomorphic** (formerly known as *conformable*) projection. For these combined reasons the stereographic projection is to be preferred to others for maps of the polar regions; it is also often used for maps of the hemispheres. It should be remembered, when the latter maps are being used, that the scale of areas at the edge is four times that at the centre.

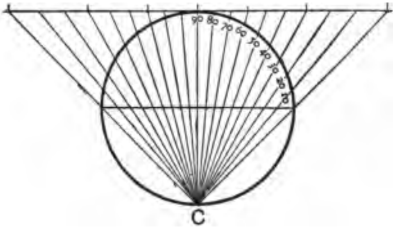


FIG. 30.—Stereographic projection.

The equidistant or globular projection.—We have found that the edge of the map—as compared with the central parts—is on much too small a scale for satisfactory work when the point of projection is at infinity (Fig. 28), and on too large a scale when the point is at the centre of the globe (Fig. 29). Though the scale of the marginal parts is still too large when the point is shifted back to the surface of the globe in the stereographic projection, it has become more nearly accurate. It is, therefore, natural to suppose that the minimum of inaccuracy in projection will be obtained by selecting some point between infinity and the surface of the globe. This point is found at a distance of $\frac{1}{\sqrt{2}}$,* *i.e.* 0·707 . . . times the radius. The distance (AC, Fig. 31) may be obtained by bisecting

* *i.e.* sin 45°.

the chord of a quadrant. It will be clear from Fig. 31, which shows the construction, that the projection thus obtained is in almost exact proportion. In practice the slight discrepancies are ignored, and the lines of latitude (in reality projected as arcs of ellipses) are, like the meridians, represented as the arcs of circles to which they closely approximate. The drawing of a map-network for a hemisphere on the equidistant or globular method is easy. Diameters of the circle at right angles to each other are first drawn, and produced indefinitely. Each radius, as well as each quadrant arc, is trisected if it is desired to represent the network at intervals of 30°, or divided into a greater number of equal parts for correspondingly closer meshes. The centres of the circular arcs required all lie on the produced diameters, and are found easily by trial.

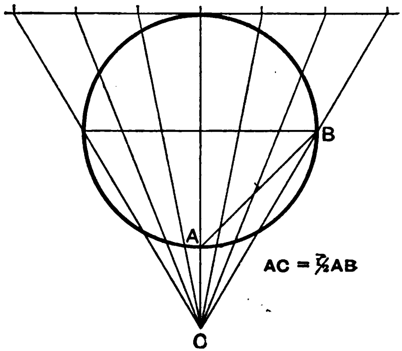


FIG. 31.—Equidistant or globular projection.

The globular projection is the conventional method of representing hemispheres, or considerable portions of hemispheres such as continents. It is obviously superior to the simple orthographic projection, though not in every respect to the "equal area" modification of the orthographic; while, as compared with the stereographic projection, it has the disadvantage of not being orthomorphic.

Simple cylindrical projections.—In cylindrical projections the network of lines of latitude and longitude is projected, not upon a plane, but upon a cylinder touching the globe along the equator. The cylinder is then spread out flat as a rectangle. If the point of projection be the centre of the globe, the network (Fig. 32) will naturally possess, in general, the qualities of the gnomonic projection (p. 52). The utility of such a projection will therefore be limited to the representation of countries adjoining the equator.

A considerable improvement, however, is obtained **by projecting the network from infinity**, that is, by parallel straight lines at right angles to the axis of the earth (Fig. 33). As before, the meridians (which, of course, on the globe converge to the poles) become equidistant parallel straight lines; but the parallels of latitude now

succeed each other at intervals which diminish from the equator to the pole, exactly as they do in the orthographic projection. The

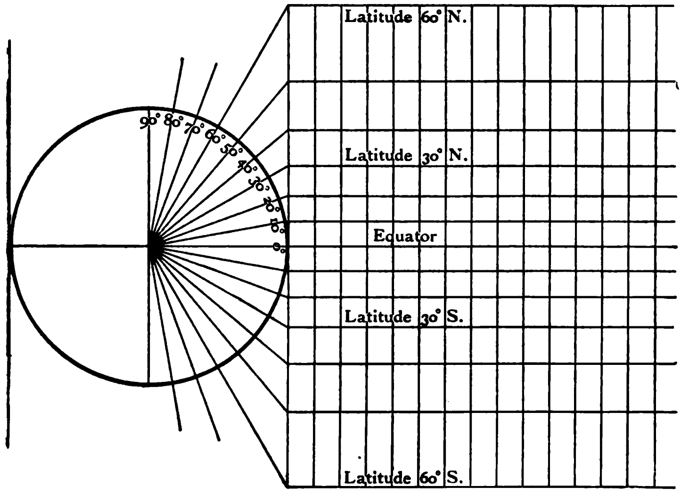


FIG. 32.—Simple cylindrical projection.

result is an "*equal area*" *projection*—that is, one in which areas all over the map are on the same scale—for, as the poles are

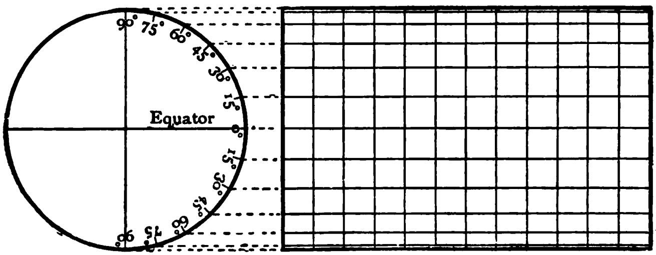


FIG. 33.—Equal-area cylindrical projection.

approached, the scale from east to west becomes enlarged in exactly the same proportion that the scale from north to south becomes reduced. The distortion in respect of shape, however, is consequently enormous.

Mercator's projection.—The geographer Gerard Kramer (better known as Mercator), who lived in the sixteenth century, invented and introduced a modification of the cylindrical method of "projection" which has been used ever since for mariners' charts. We have seen that in a cylindrical projection the meridians, which on the globe converge towards the poles, are mapped as parallel straight lines, so that distances measured from east to west are exaggerated on the map to an extent which increases as the poles are approached. Mercator's improvement consists in also exaggerating distances north and south in the same proportion. The result is that, although the scale of the map increases very much from the equator to the poles, a correct shape is everywhere preserved, and a straight line drawn on the map between two places shows the actual direction (expressed in terms of the compass card) from one to the other. Such a line is called a **rhumb line.** In other words, Mercator's projection is **orthomorphic,** and this is the quality which makes it so valuable in navigation. For other purposes, its chief advantage is that it shows the whole surface of the earth on one map.

The principle of Mercator's projection may be illustrated more exactly by the following examples: Measured along the equator, 1° of arc is equal to 69·15 miles, while at latitude 30° the meridians have converged so much that the distance between two meridians 1° apart is only 59·94 miles. A cylindrical projection, however, shows meridians everywhere the same distance apart; that is, the scale in an east-and-westerly direction is here enlarged 69·15/59·94 times. On Mercator's projection, therefore, two parallels of latitude 1° apart would, at this distance from the equator, also be shown 69·15/59·94 times as far apart as a meridian-degree at the equator. At lat. 60° the meridians on a globe are only half as far apart as at the equator. On Mercator's projection, therefore, *all* lengths at this latitude are shown on twice the scale of lengths at the equator, and consequently all *areas* at lat. 60° N. or S. are on four times the equatorial scale. At lat. 70° areas are represented on 8½ times, and at lat. 80° on 33 times the scale of areas at the equator. Unless this great increase of scale towards the poles be borne in mind constantly, when a map on Mercator's projection is being used, very erroneous impressions of the relative sizes of countries will be obtained.

Since on the surface of a sphere the shortest line between any two points must form part of a great circle, it follows that the shortest course between two ports *on the same meridian* lies along that meridian, and is therefore represented on Mercator's projection by a straight line. Similarly, the shortest course between any two

ports *on the equator* is represented by a straight line on Mercator's projection. All other great circles are, however, represented by curved lines in this projection. It follows that the shortest course between two ports which do not both lie either on the same meridian or on the equator (*e.g.* two ports of lat. 40° S.) would be shown by a curved line on Mercator's projection. It is evident that in "high" latitudes **great circle sailing**, in preference to keeping to the compass direction shown by Mercator's chart, often effects a considerable saving in distance and time to a ship. In general, the advantage of steering by a straight line on a Mercator's chart, and thus of being able to set a course to a definite point of the compass, outweighs the slight lengthening of passage.

The conical projection.—In this class of map-network, which is in general use for all countries not extending through much more than 30° of latitude, the lines of latitude and longitude are supposed to be projected from the centre of the globe on the surface of a cone, fitting on the globe and having its apex on the produced axis of the globe. Two tangents drawn at any given latitude will meet in the axis produced, making an angle with each other which is twice the angle of latitude; and it is obvious that by varying the apical angle, the cone may be made to touch the globe along any desired parallel of latitude except the equator. In the projection, the meridians are represented by straight lines, radiating from the apex of the cone, and the parallels of latitude by arcs of concentric circles of which the centre is the same point.

In practice greater accuracy is secured by supposing the cone to *cut* the earth in two parallels intermediate between the central parallel and the two extreme parallels.

The method of conical projection may be illustrated by a detailed explanation of the **construction of the map-network of a country**, say England and Wales.

In this example, the range of longitude is from 2° E. to 6° W., and the central meridian on the map will therefore be that of 2° W. The latitude extends from 50° N. to 56° N., so that the country is well within the limits (30°) for which a conical projection is suitable. A scale of miles is first drawn, such that the map may nearly fill the space available. The central meridian is drawn, and on it the intersections of the parallels of latitude (50° to 56° inclusive) are set out to scale. On so small a map as Fig. 34, one degree of the meridian may be taken as 69 miles.* The middle parallel is that of 53° N., and we may suppose the cone

* At lat. 50°, 1° of the meridian measures 69.11 miles.
,, 60°, 1° ,, ,, 69.21 ,, (p. 68).

to cut the globe at 51° N. and 55° N. (51½° and 54½° being respectively half-way between the middle and the two extreme parallels would theoretically be better, though in this case not appreciably better).

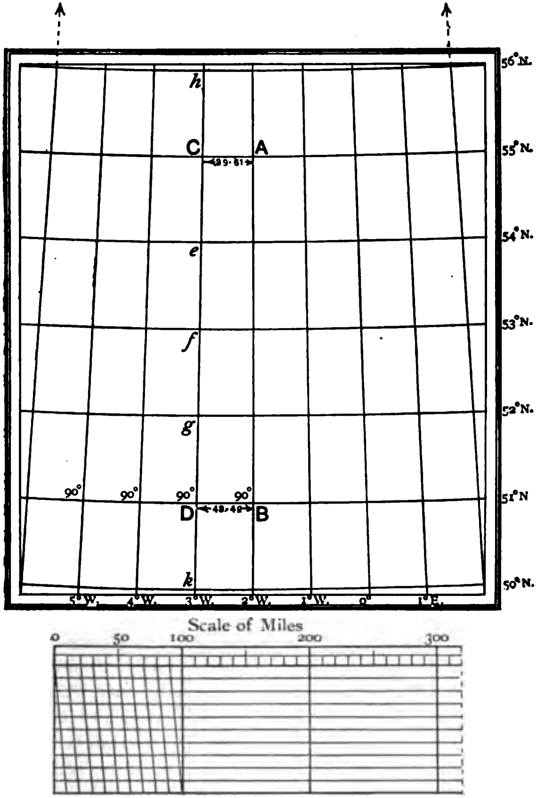


FIG. 34.—Conical projection. Method of drawing the map-network of England and Wales.

Now, along lat. 51°, 1° measures 43·42 miles; while along lat. 55°, 1° measures 39·61 miles. At 51° and 55°, therefore, short straight lines of the respective scale-lengths of 1° are drawn east and west at right angles to the middle meridian. The figure *ABCD* is thus obtained, and the points *e*, *f*, *g*, *h*, *k* are determined by drawing lines parallel to *AC* or *BD* to cut *CD*, the

meridian of 3° W. To repeat this strip on both sides and complete the network, the intersections of the lines are carefully marked on tracing-paper, and "pricked off" separately for each meridian. Points of the same latitude may be joined up by straight lines, for on the small scale of this map one degree of a parallel of latitude does not differ appreciably from a straight line; but on a larger scale or with a map extending over a greater number of degrees of longitude, the parallels would be drawn as arcs of circles from the centre found at the intersection of the extreme meridians of the map, produced as shown by the arrows.

The advantages of the conical projection are that

(1) all meshes between any two given parallels of latitude are of the same shape, and consequently the sides of the map are not distorted as compared with the centre;

(2) within the limits of latitude—about 30°—to which a map on this projection is generally restricted, there is no appreciable change in the shape of the meshes even from north to south, especially if the cone is supposed to cut the globe along two parallels; and

(3) it is possible to make all the meridians, as well as the two selected parallels, true to scale.

Equal-area projections.— Besides the equal-area modifications of the cylindrical (Fig. 33) and orthographic (p. 50) projections already described in this chapter, other and better equal-area networks are in common use. One of the most generally useful—because it shows the whole earth on one map, and with relatively little distortion of the shapes of countries—is known as the **elliptical equal-area network.** In shape the map is an ellipse, the major axis of which, representing the equator, is twice the length of the minor axis, which represents the central (usually the prime) meridian. For a network of 10° mesh the central meridian is divided into 18 equal parts, and the equator into 36 equal parts. The parallels of latitude are straight lines parallel to the equator, and the meridians are ellipses drawn through the poles and the divisions of the equator.

Equal-area networks are naturally most useful for maps intended to show the relative *extent* of areas displaying some specific character, *e.g.* foreign possessions, distribution of races, crops, minerals, density of population, rainfall, etc. It is plain that such maps ought to be provided with a scale of areas, stating the number of square miles represented by, say, one square inch, instead of a linear scale, which at best can be only approximate.

Fig. 35 shows in the case of Alaska—selected on account of its

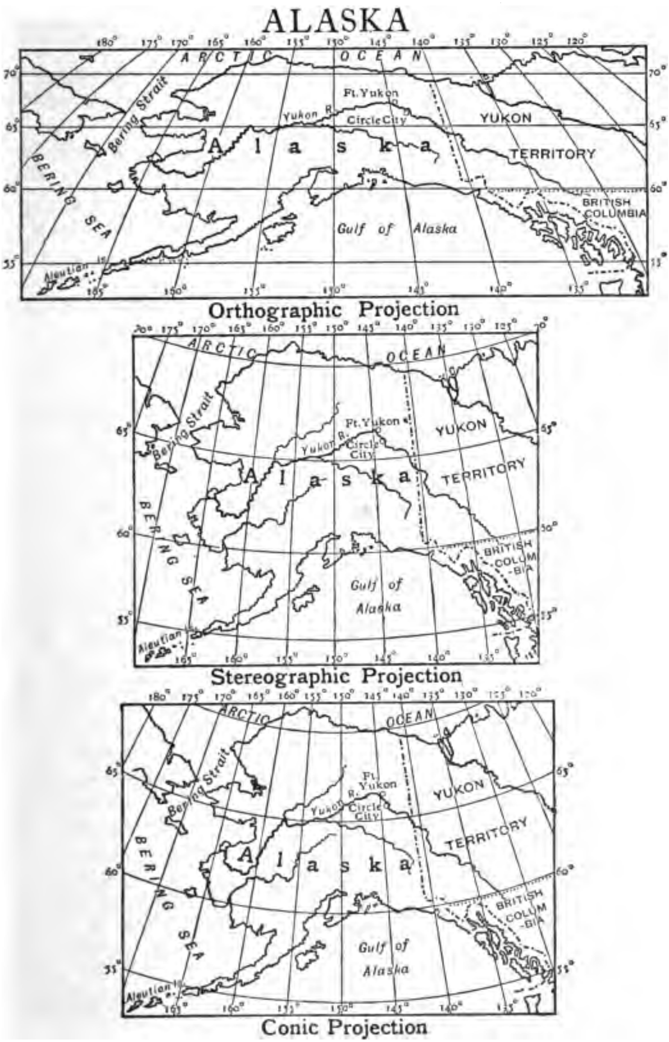


Fig. 35.—Alaska on three different projections.

high latitude—how the shape of a country may vary when drawn on different projections.

EXERCISES ON CHAPTER III.

1. What is meant by Latitude and Longitude? Is there any difference in the lengths of degrees of Latitude and Longitude? Explain.

2. Explain how to draw the meridians and parallels of latitude for a map of the hemisphere on the orthographic projection. (C.S.)

3. What are the special advantages and disadvantages of a map on an "equal area" projection? Mention any purposes for which you would prefer to use such a map. (O.S.)

4. State exactly what is meant by the term map-projection, and explain (*a*) how the chief difficulty of map-making arises, and (*b*) the different qualities that are possessed by different projections. (L.M.)

5. Explain the method on which a Mercator map is made, and state the advantages and disadvantages of this projection. (C.S.)

6. Give the construction of a network of latitudes and longitudes which will show areas truly.

What are the advantages and disadvantages of a map on such a network? And for what purposes should you select it? (L.M.)

7. What is meant by Mercator's Projection? Explain its principle, illustrating your answer with diagrams. Point out the chief errors of this system of projection and state for what purposes it is chiefly used and why.

8. For what special properties are the following projections respectively useful: Gnomonic (central), stereographic, globular, conical, Mercator's?

9. Describe three varieties of cylindrical projection, and in each case mention the most important property.

10. Which do you consider the best projections to use (*a*) for showing the size of the British Empire, (*b*) for laying down a route for crossing the Atlantic by airship, (*c*) for comparing the directions of mountain-chains or of coast lines, (*d*) for comparing the areas of the African and North American lakes? Give your reason in each case.

11. What is the difference between a "great circle" and a "small circle" on the globe?

Explain why the shortest distance between two places on the same meridian is along that meridian, but the shortest distance between two places on the same parallel of latitude is not, in general, along that parallel. (O.J.)

12. Compare the special uses, for purposes of navigation, of the gnomonic and Mercator's projections.

13. What are the advantages of orthomorphic map networks? Give a general description of two such networks.

14. What is meant by "great-circle sailing"? In what circumstances is it advantageous?

CHAPTER IV.

THE EARTH AS A PLANET.

9. THE SHAPE OF THE EARTH.

1. The earth's shadow.—Look in any good almanac of the current year for the date and time of the next eclipse of the moon; and, if it is visible where you are, take the opportunity of studying the earth's shadow which is then thrown on the moon.

2. Other shadows.—Project, by means of a candle placed, say, 10 ft. from a white screen, the shadow of (*a*) a ball, (*b*) an egg, (*c*) a circular disc. Study the form of the shadows as the objects are rotated. Of how many of the objects is the shadow always circular?

3. The horizon. (*Outdoor work.*)—Observe the curvature of the horizon of any large and flat expanse, *e.g.* the surface of the sea or a wide plain. What angle with the horizontal is made by a telescope pointing to an object on the observer's horizon? Is this angle the same whether the observer is standing on the shore or on a high cliff? Can the same point be on the horizon of two persons at different heights? How does the distance of the horizon vary as you respectively (*a*) lie, (*b*) sit, (*c*) stand on the sea shore, and (*d*) climb a cliff or hill? Why are lighthouses placed on elevated positions rather than on the sea level? Which part of a ship approaching port comes into view first? What prevents the rest of the ship from being seen so soon? What would be the possible shapes of the visible limit (horizon) of (*a*) a cricket ball, (*b*) an egg, to an insect walking over its surface?

4. Oblate spheroid.—(*a*) Procure a circular hoop of thin steel, and support it upon an axis attached to a whirling-table as shown in Fig. 36. Set it spinning by turning the handle of the whirling-table. Notice that the hoop assumes a more flattened form. The flattening is increased as the rate of spinning is made greater.

(*b*) Mix rectified spirits and water until a few drops of oil just float on the mixture when it is quite cool. Pour fresh oil, by means of a pipette, into the middle of the mixture, and notice that a spherical

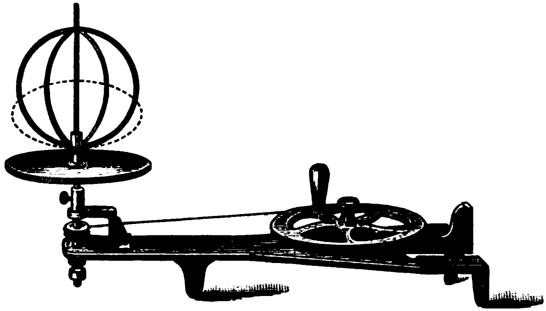


FIG. 36.—Apparatus to show the flattening produced by spinning a flexible steel hoop.

globe of oil may thus be formed. By means of a glass rod set the liquid spinning, and observe that the globe of oil assumes a flattened form when it is made to rotate.

5. The altitude of the pole star. (*Outdoor work.*)—Obtain two thin rods of wood about a foot in length. Place the two together and push a pin through them both near one end, so as to hold them like the legs of a pair of compasses. Using either a rough arrangement of this kind, a clinometer (p. 19), or a better instrument if one is available, estimate the angle which the direction of the pole star (p. 6) makes with the horizon. Compare this angle with the latitude of your position.

The form of the earth.—The history of the different ideas which men have had respecting the shape of the earth forms an interesting example of the change in attitude of man's mind towards all questions as his knowledge increases. In early times the most fanciful notions respecting the earth's form found ready acceptance, and even in recent time so-called proofs of the globular shape of the earth were accepted which were really not proofs at all. At present we believe that the earth is more or less spherical, that is, more or less round like a ball, for such reasons as the following:

(1) *The shape of the earth's shadow cast upon the moon during lunar eclipses is always circular.* We know from geometry and

experiment that the only solid which always gives a circular shadow, wherever the light which throws it is situated, is the sphere. Because the outline of the earth's shadow is always circular (Fig. 37), whatever may be its position with regard to the sun, we feel justified in asserting that the earth must be a more or less perfect sphere. From other considerations we believe that the sphere is not perfect, but flattened towards the two poles.

FIG. 37.—Photograph of an eclipse of the moon showing the curved form of the earth's shadow.

(2) *The dip of the horizon to right and left is everywhere the same. In consequence it appears circular to an observer raised above the earth's surface.* It is characteristic of a sphere that, from whatever point it is viewed, it always appears circular; and since the horizon, that is, the line where earth and sky

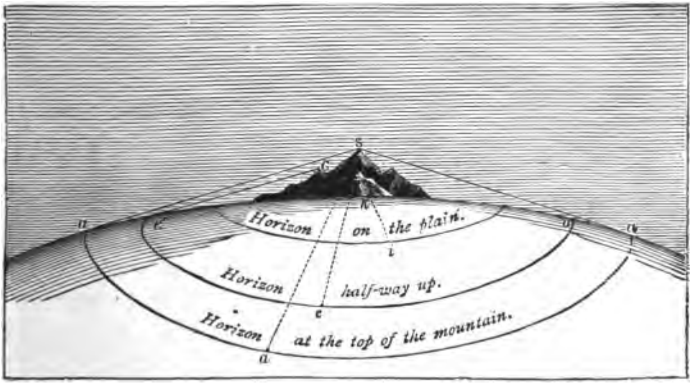


FIG. 38.—The horizon is always circular.

appear to meet, bounds a circular space at whatever altitude the observer is situated, and wherever he may chance to be upon the earth's surface, it is evident that this reason alone

gives us strong grounds for asserting that the earth is round like a globe.

(3) *The times of rising, southing, and setting of the sun and stars are different at places situated on different meridians.* If the earth were flat, as soon as the sun appeared above its edge it would be visible throughout the earth's surface. But this is by no means the case. Similarly, the sun—being at a very great distance—would "south," *i.e.* attain its highest position in the sky, at an instant which would be the same for all parts of a flat earth. This, too, is just as far from the truth. When it is noon at Greenwich it is 7 a.m. at New York and 6 p.m. at Calcutta, so the sun may be rising at the former place and setting at the latter. This reason should be reverted to after the section on longitude and time (p. 80) has been read.

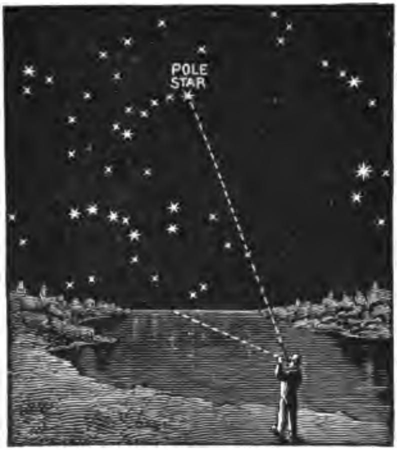


Fig. 39.—The altitude of the pole star is approximately equal to the latitude of the place of observation.

(4) *The altitude of the pole star regularly increases as the observer travels from the equator to the poles.* If the surface of the earth were horizontal the altitude of the pole star—the star being at "infinite" distance—would be the same from whatever place it was viewed. But observation shows beyond a doubt that as we travel northwards the altitude gets greater and greater until at the north pole the star would be exactly overhead, or its altitude would be 90°. If we travel in the reverse direction, the reverse changes occur; the altitude of the pole star diminishes from 90° at the pole until at the equator the pole star appears on the horizon, or its altitude is 0°.

To bring about these changes in the altitude of the pole star, it is clear that the observer must himself have described an angle of 90°, for the change in the observer's position could have no actual effect upon that of the pole star. Hence in travelling from the pole to the equator the observer describes one-quarter of a circle, and if he went right round the earth he would cover $4 \times 90° = 360°$, or a complete circle. A little thought will show, also, that the

altitude of the pole star must always be equal to the latitude of the observer.

Measurement of the earth's circumference.—The earth is, for the reasons given, considered to be spherical in form, and it will be desirable now to consider how the length of a line round the earth has been determined. A line encircling the earth, and passing round it in such a way that the plane containing it passes through the centre, is called a great circle, or circumference of the sphere. We can ascertain the length of such a circle from the following considerations.

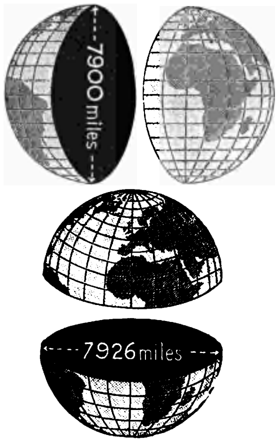


FIG. 40.—Polar and equatorial diameters of the earth.

From the last of the reasons given above for believing the earth to be spherical, we know that to make a difference of one degree in the altitude of the pole star we must travel through an angle of one degree measured along a meridian of the earth. The plan to be adopted, therefore, is to travel northwards or southwards for such a distance along a meridian as to cause a difference of one degree in the altitude of the pole-star. When this has been done $\frac{1}{360}$ part of the circle round the earth has been traversed, and consequently to determine the circumference it is merely necessary to multiply the distance travelled by 360. It has been found that the distance to be travelled to bring about such an alteration of one degree in the pole star's altitude is not always the same. As the poles are approached this distance becomes greater. No difference whatever in altitude would be produced on a flat earth, and it may be argued that since for a given journey the difference in altitude produced is less towards the poles we must be travelling on a flatter earth, *i.e.* the earth is flattened somewhat near the poles. These varying lengths are, of course, the lengths of degrees of latitude along different portions of meridians.

Variation of degrees of latitude.—In travelling from the equator to the poles, then, there is a gradual increase in the length of a degree of latitude. The amount of such difference will be seen from the following table:

Latitude	Distance travelled to bring about difference of 1° in altitude of pole star = length of 1° of latitude.
Equator	68·69 miles
10°	68·70 "
20°	68·77 "
40°	69·00 "
60°	69·21 "
80°	69·38 "
Pole	69·39 "

By taking an average value of the lengths of these degrees of latitude, say 69 miles, and multiplying it by 360, we obtain 24,840 miles as the length of 360 degrees, or a complete circle round the earth; and if this is divided by $3\frac{1}{7}$ (the ratio of the circumference of a circle to the diameter) the diameter is found to be 7918 miles.

Exact shape of the earth.—A globular body flattened towards two points, situated as far as possible away from each other, is called an **oblate spheroid.** The points of flattening are called the *poles*, and the line joining the poles is known as the *axis.*

It is usual to describe the earth as having the form of an oblate spheroid, but this is not strictly true. It is now admitted by all physical geographers that the earth is very slightly flattened at the equator as well as at the poles; that is to say, a belt placed round the earth at the equator would not be a circle, but very slightly elliptical in shape. Moreover, recent polar explorations have shown that though the crust of the earth in north polar regions is greatly below sea level, the reverse is the case in south polar regions, which consist of high and mountainous land, the mean height of the Antarctic continent being probably about 2000 metres. Grossly exaggerating, we may say that the earth is pear-shaped, with the stalk in the south; but of course the difference between the level of the north and south polar regions is relatively insignificant. No common object can really represent the shape of the earth, nor can a geometrical term express it. Perhaps the best word to use is **geoid,** which signifies merely earth-shaped.

A careful examination of terrestrial ridges, elevated areas and depressions shows that the earth's form approaches that of a tetrahedron, which is a solid body having four faces, six edges, and four corners. The earth is not, of course, tetrahedral in the ordinary sense of the word, but when the distribution of land and water and the courses of the main watersheds and mountain chains are examined critically, ridges are found in the approximate positions of the edges of a tetrahedron, and slight flattenings between them suggesting the faces of a tetrahedron. There is good reason to believe, even if no actual evidence were available, that the earth must tend towards this shape; for a globe of plastic material surrounded by a hard crust gradually assumes the form of a tetrahedron as it cools; and the earth appears to be an example of this fact on a large scale.

The following passage shows how slight, nevertheless, is the departure of the earth's shape from that of a sphere. "As to the smoothness and roundness of the earth, if represented by an 18 inch globe the difference between the greatest and least diameters would be only about $\frac{1}{16}$ of an inch. The highest mountains would project only about $\frac{1}{76}$ of an inch, and the average elevation of continents and depths of the ocean would be hardly greater on that scale than the thickness of a film of varnish. Relatively the earth is much smoother and rounder than most of the balls in a bowling-alley." *

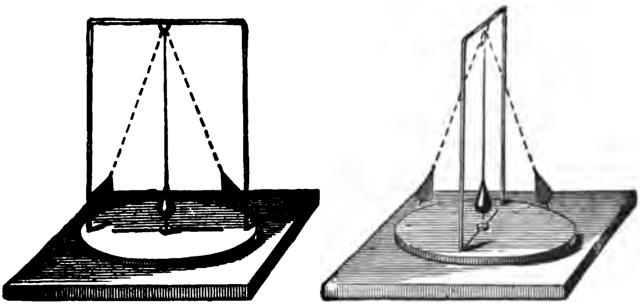


FIG. 41.—Model to show that the fine wire suspending a vibrating weight can be twisted without changing the direction of vibration.

10. THE ROTATION OF THE EARTH.

1. Model of Foucault's pendulum.—Swing a heavy ball suspended freely by a fine wire from a point fixed to a support which rests

* Young's *Manual of Astronomy* (Boston and London: Ginn & Co.).

on a board that can be moved round as required (Fig. 41). Let a hog bristle attached to the ball just touch the board, and on the board place a very smooth piece of paper which has been held close over a piece of burning camphor until coated all over with black. Cause the pendulum to swing, by moving it to an angle with the vertical by a piece of thread and then cutting the thread with scissors. Slowly rotate the board round a centre. It will be found that the ball swings in the same direction, as regards the room, as that in which it originally started, and regardless of the motion of the board.

2. **The apparent diurnal motion of stars.**—(*a*) On a clear night fix on any bright star (i) when facing north, (ii) when facing south, and note its position in the heavens. In each case, observe the star again an hour later. Is it in the same position as before? If not, in what direction has it moved in the meantime?

(*b*) Take up a position to the south of a convenient vertical line, *e.g.* a telegraph post or the corner of a building. You can do this by sighting the pole star against the line. Observe that a star above the pole star attains its highest point in the sky as it passes behind this vertical line from east to west, whereas a star below the pole star is at its lowest point and passes from west to east. Note by your watch the time of passing the line, and see if the same star passes the same point at the same time on the following night. If you can find a wall, the face of which lies exactly north and south, you can similarly, from a position to the north of it, observe when stars are due south and at their highest points.

(*c*) Focus a camera at the pole star, put in a sensitised plate, and expose it for a couple of hours. Then take out the plate and develop it.

3. **Angular measurement applied to the sky.**—(*a*) Using an arrangement such as is described in Expt. 5, Sec. 9, or a better instrument if one is available, measure some angular distances between stars. For instance, point one of the legs of the instrument to the pole star, and the other to the nearer of the pointers; then place the legs so that their junction lies at the centre of a circle divided into degrees, and determine the angle between them.

(*b*) In the same way measure other angular distances, such as those between the following stars (Fig. 3): (i) the two extreme stars in the Plough; (ii) the pointer (α) nearest the pole star, and the star marked η in Ursa Major; (iii) the pole star and ϵ in Cassiopeia; (iv) Capella and the pole star. Find out whether the angular distance between two selected stars varies at different times, or is always the same.

4. **Circumpolar stars.**—On a clear night open the jointed rods to

an angle equal to the latitude of your position, and observe which stars are included within this angular distance from the pole star. These are the stars which are always visible from your latitude when the sky is clear. Other stars "set" on the western horizon once a day, and are out of view until they "rise" again on the eastern horizon.

5. Experimental illustration of rotation.—Place a small ball or globe upon a table. Stick a long pin into the globe in any position. Rotate the globe on its axis so that the northern hemisphere moves in the opposite way to the motion of the hands of a watch. Notice that the pin is turned in succession towards different objects upon the walls, floor and ceiling of the room, which may be regarded as stars in the heavens. If the globe rotated at a uniform rate, the period of rotation could evidently be determined by observing the interval between two successive appearances of any one star in the same position.

6. Day and night.—Light a a lamp to represent the sun, and place the globe near it. One half of the globe is illuminated, and the other hemisphere is in darkness. Rotate the globe as before; different parts are thus successively turned into the light and darkness. The rising and setting of the sun can thus be shown to be explained by the rotation of the earth on its axis from west to east.

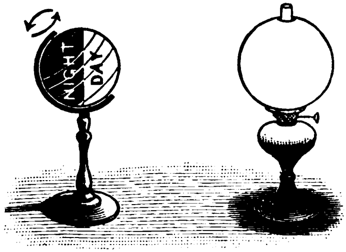


FIG. 42.—Experiment to explain the cause of day and night.

Rotation of the earth on its axis.—The earth spins on its axis in a manner which resembles the spinning of the globe in Expt. 10, 5. This spinning motion constitutes **rotation**. In the case of a globe rotating upon a needle without thickness as axis, it is apparent that the axis itself is free from any spinning motion, while the parts of the globe farthest away from the needle move through the greatest distance in a given time, or have the highest velocity. Similarly with the earth, the poles are at rest, while places on the equator are carried through a distance of about 25,000 miles in the time of one rotation, which is twenty-four hours; that is, they have a velocity of over 1000 miles an hour.

The rotation of the earth causes day and night.—The sun and the earth are bodies in space; the sun is luminous, while the earth is a dark body with no light of its own. The sun sheds its light in every direction, and lights up that half of the earth which is nearer to it, the remote half meanwhile being in the dark (Fig. 42). Were the earth at rest this would be so always; one-half would be illuminated always or enjoy the brightness of day, the other would be in the perpetual darkness of night. But since the earth is rotating, new parts of our planet are being brought constantly "out of darkness into light." The night is followed regularly by the day, and as the spinning carries any place round, it is in due course taken out of the sunshine into the shadow of evening again.

Proof of the earth's rotation.—The apparent daily motions of the sun and stars are a direct consequence of the earth's rotation, but a moment's thought is enough to show that exactly the same appearances would be observed were the earth, as was originally thought, the rigid centre of a moving universe. If the earth were fixed, while the heavens moved round it as a centre once in twenty-four hours, we should have just the same alternation of day and night, and the identical succession of rising, southing (p. 66) and setting of the celestial bodies. The movements of the spots on the sun across its disc afford evidence of its rotation, and, judging from analogy, we have a strong probability of the earth's rotation. But, fortunately, direct proofs are to hand.

The experimental proofs of the earth's rotation may be summarised as follows:

1. By the observation of bodies falling from a great height towards the earth. Such falling bodies are deviated towards the east.
2. By experiments with Foucault's pendulum.
3. By experiments with Foucault's gyroscope.

Foucault's pendulum.—Newton's **First Law of Motion** asserts that *every body continues in its state of rest or of uniform motion in a straight line until it is compelled by impressed force to change that state.* This statement of one of the properties of matter is admitted on all hands to be true, and Foucault made use of the property to demonstrate the earth's rotation. If a heavy pendulum is set oscillating, it resists any attempt to force it out of the plane in which it is swinging. Expt. 1, Sec. **10**, shows this prettily on a small scale. Foucault, making use of the fact

which the experiment illustrates, suspended a heavy iron ball, by means of a long, thin wire, from the roof of the Panthéon in Paris. This pendulum was pulled out of the vertical and held on one side by a thread attached to the wall. The pendulum was then allowed to swing to and fro over a circle of sand on the floor. The experiment can, however, be done satisfactorily if a table on which marks have been drawn be substituted.

The pendulum is set swinging by burning the thread. As time goes on the suspended weight seems to pass along a different line on the table from that originally traversed, and it is clear that one of two things must have happened—either the plane of the pendulum's oscillation must have altered, or else the table must have turned round. But Expt. 1, Sec. **10**, shows that the former alternative is impossible, and we are forced to the conclusion that the table, and therefore the earth of which it is a part, gradually turn round. If the experiment were performed at either of the poles the table would turn completely round once in twenty-four hours.

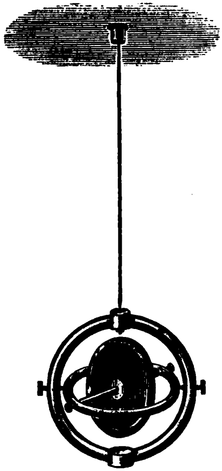


FIG. 43.—Foucault's gyroscope. For explanation, see text.

Foucault's gyroscope.—The gyroscope is a device which Foucault employed later for demonstrating the rotation of the earth. The method is not so satisfactory as the pendulum plan, though the principle involved is identical. A heavy disc (Fig. 43) having an axis which turns easily upon pivots, is made to rotate at a high velocity. The rapid revolution of the disc in one plane gives the gyroscope rigidity; consequently a pointer rigidly fixed to the outer ring of metal will remain perfectly still, while the earth will rotate under the gyroscope and carry with it a scale, the instrument, and the table on which they are fixed.

Apparent movements of the stars due to the earth's rotation.—Attention has been directed (p. 66) to the difference in altitude of the pole star which is noticed as an observer travels from the equator towards the poles. The changes may now be considered which are noticed in the apparent movement of the stars as we move either from the equator towards the poles or in a contrary direction. An examination of Fig. 44 makes the matter clear. To

take in order the three positions of the observer depicted in the illustration :

1. **When the observer is at either of the poles,** say the north, the pole star appears almost exactly overhead : indeed it is so named because if the earth's axis were continued to meet the heavens it would pass almost exactly through this star. The horizon is contained by the plane passing through the earth's equator. All stars

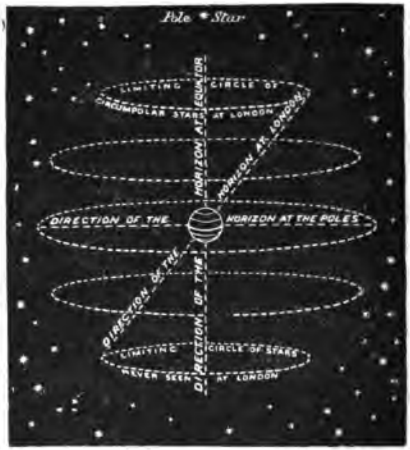


FIG. 44.—To explain the difference in the apparent diurnal motions of stars when observations are made in different latitudes.

appear to move round the observer in circles, and remain visible throughout their daily journey. Or, it may be said that their apparent paths are always parallel to the horizon.

2. **When the observer is at the equator** the pole star appears on the horizon, and all stars seem to describe semicircles in the heavens. The planes containing the paths of the stars are vertical.

3. **When the observer is in middle latitudes,** say at London, the stars seem to belong to three classes : (i) Those which can be seen throughout the whole of their apparent journey, that is, which never set (these are called *circumpolar stars*) ; (ii) those which are visible for only a part of their apparent path, that is, which both rise and set ; (iii) those which never come into sight

at any period of their apparent daily motion, that is, which never rise.

Apparent motion of stars.—If the northern sky be watched on a fine night all the stars will be seen to turn as if they were fixed on a solid vault pivoted at a point near the pole star (Fig. 45). A

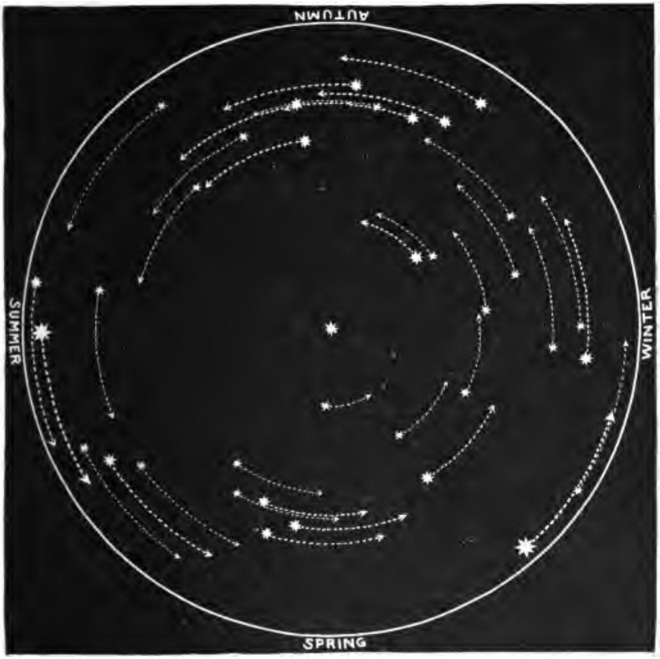


FIG. 45.—Apparent rotation of stars around the north celestial pole. Arrange the diagram so that the name of the season can be read at the bottom, and the stars then occupy the position in which they can be seen about 10 p.m. (Compare with Fig. 3.)

striking way of showing this is afforded by photography. Whilst the camera is directed towards the sky the stars apparently move round the pole star, the result being that they all leave trails upon the photographic plate (Fig. 46). The pole star traces an arc of a very small circle (thus proving that it is not situated absolutely at the pole), while the other trails are arcs of much larger circles.

A similar result is obtained if a photograph is taken of the region around the pole by a photographer in the southern hemisphere. This indicates that the earth *is* in rotation.

FIG. 46.—Photograph of the apparent rotation of stars round the north celestial pole.

11. THE LENGTH OF A DAY.

1. Greenwich and local times.—Cut out a ring of cardboard large enough to encircle completely a ball or globe with one or two inches between the inner rim and the surface of the globe. Mark 24 divisions around the ring to represent hours, and number them from i to xii in each half of the ring, letting the numbers read in the opposite direction to those upon the dial of a clock. Place the globe near a lighted lamp, with its axis vertical, and fix the ring on a level with the equator so that one number xii is directed towards the lamp (Fig. 47). Stick a long pin into the globe at the equator on the meridian passing through Greenwich. This pin will serve to show the hour division over the Greenwich meridian at any time. Rotate the globe and

notice (*a*) that the Greenwich or any other meridian passes in succession under each of the twenty-four hours marked upon the ring; (*b*) that the time of day at any place depends upon the position of the

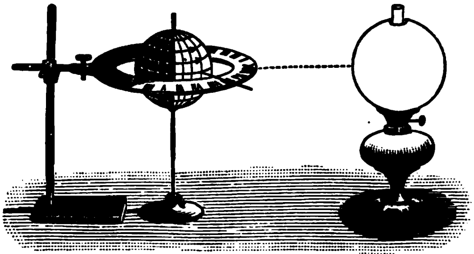


FIG. 47.—Model to illustrate the relation between time and longitude.

place with reference to the sun; (*c*) that if Greenwich time, as shown by the pin, and the time at any place at the same instant are both known, the longitude of the place can be determined.

2. Construction of a sundial.—Obtain a small slab of wood, about a foot square, and varnish the top so that a fine circle can be drawn upon it in ink, or glue paper upon it, and after drawing the circle varnish the paper. Draw a diameter of the circle, and place the slab so that this diameter is due north and south and the sun can shine upon it. Fix a knitting needle at the centre of the wood and inclined to it towards the north at an angle equal to the latitude of the place of observation (Fig. 48). The needle then points towards the North Celestial Pole, and is parallel to the earth's axis. Notice the position of the shadow of the rod at definite hours, say 9 a.m., 10 a.m., 11 a.m., noon, 3 p.m., 4 p.m. Draw a line from the centre of the circle in the direction of the shadow at each observed time. You will notice that the shadow does *not* move through the same angle every hour. In our latitude, therefore, the dial of a sundial must not have the hours marked at equal intervals like the hours on the dial of a clock.

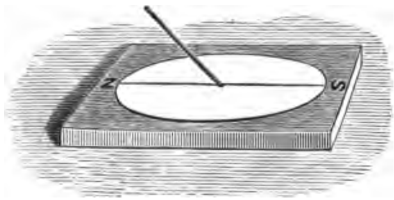


FIG. 48.—Simple horizontal sundial.

3. Apparent daily motion of the sun at the poles.—Draw a circle upon paper or thin cardboard, and divide it into 24 equal parts

by drawing lines 15° apart from the centre to the circumference. Number these lines from i to xxiv to represent hours. Fix the circle upon a board or table and stick a knitting needle or thin rod upright at its centre. Place a lamp so that the shadow of the needle can be

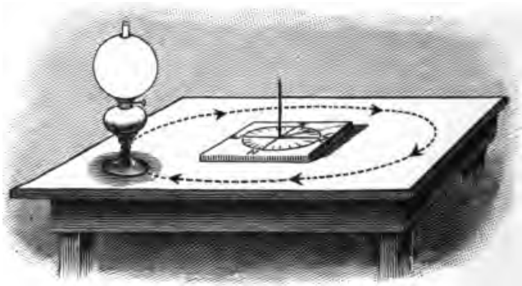


FIG. 49.—To illustrate a sundial at the north pole, and the apparent diurnal movement of the sun there.

seen clearly. Carry the lamp round the needle in the way indicated in Fig. 49, and notice the change of direction of the shadow of the needle. At the poles the sun appears to move round the heavens parallel to the horizon in this way during the summer.

4. Construction of sundial for any latitude.—Cut out of cardboard another circle of the same diameter as that in the preceding experiment, and push the knitting needle through its centre. Incline this upper circle so that the knitting needle makes an angle with it equal to the latitude of the place for which the dial is to be divided. Fix the circle in this position by means of a clamp. Place a set-square vertically against each of the twenty-four divisions of the lower circle, and make a mark where it touches the upper one. Now take off the upper circle and draw a line from each mark so obtained to the centre of the circle. These lines represent the hours, the line which was at the lowest part of the card being 12 midnight and the opposite one 12 noon.

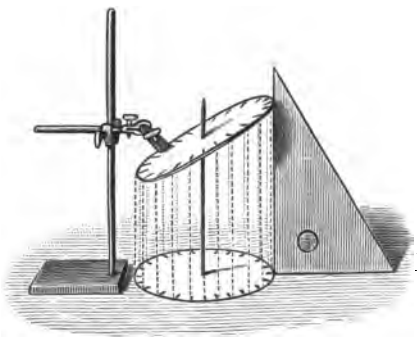


FIG. 50.—How to graduate a sundial for any latitude.

Apparent daily motion of a star.—Most of the stars, like the sun, rise, south, and set. But whereas with the sun the interval between two successive passings across the meridian varies throughout the year, it is found that the time which elapses between two successive similar southings of the same star at any season of the year is always the same. This interval constitutes a star day or **sidereal day**. If, then, some means of ascertaining the exact moment at which a star passes over the meridian of a place can be found, we have a method of measuring time in terms of an interval of time which is always the same.

FIG. 51.—Cooke's form of transit instrument.

The **transit instrument** affords us such a means. It consists of an astronomical telescope which is fixed firmly between two vertical uprights and supported so that it can move round in a vertical plane (Fig. 51). The eye-piece of the telescope is provided with cross-wires, some vertical and one or two horizontal. When the telescope is moved round, the middle vertical cross-wire traces out a line which passes through a point exactly overhead, called the *zenith*, and also (for the instrument is so fixed) through the north and south points on the horizon. The line thus traced out is, of course, the *meridian*. When, therefore, the image of a star crosses this vertical cross-wire, or **transits**, as we say, we have the exact moment of the

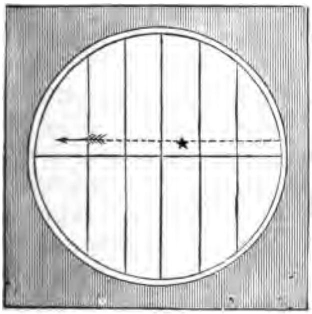


FIG. 52.—Spider lines in the field of view of a transit instrument. The middle vertical line marks the meridian. The direction of motion is that seen with an inverting telescope.

star's *southing* (Fig. 52). The interval between such an observation and a similar one with the same star the next night is an exact sidereal day.

Greenwich and local times.—Let the reader suppose himself above the earth, in the zenith of the north pole, and looking down upon the north pole situated at the intersection of the diameters of the circle which represents the equator of the earth (Fig. 53). The circle is divided into 24 equal parts, and hence the angle between any radius and the next is 360° divided by 24, or 15 degrees. As the globe spins round, each radius in turn occupies

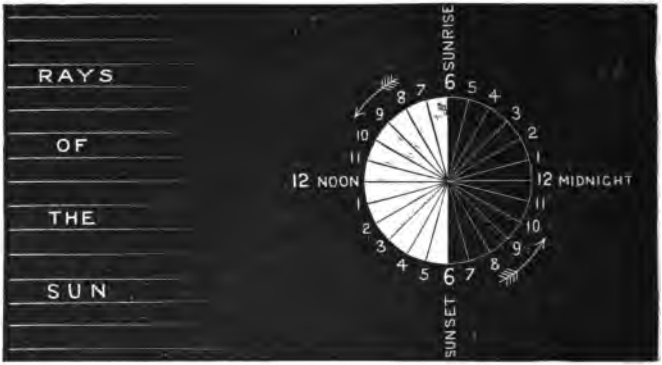


FIG. 53.—Relation between time and longitude. (For the sake of simplicity, the earth is shown illuminated as it would be at the equinoxes (p. 96).)

the position of that marked "12 noon." An observer at a place with this longitude will see the sun in its highest position for the day, or on the meridian. The observer situated on the earth at the opposite end of the same diameter will be as far away from the sun as he can possibly be. Or, at places of longitude 180° it will be 12 o'clock midnight when at Greenwich it is 12 o'clock noon. When the sun is on the meridian at Greenwich, it will be 6 o'clock in the morning and 6 o'clock in the evening respectively at places 90° W. and 90° E.

Again, when it is 12 o'clock noon at Greenwich, at places 15° W. longitude it is 11 a.m., while at places 15° E. longitude the sun has passed the meridian an hour ago, or it is 1 p.m.

Hence **the rule for finding Greenwich time** at a place when

the local time and the longitude of that place are known. For places west of Greenwich add to the local time one hour for every 15° of longitude, or four minutes for every degree; while, for places to the east, subtract the same amount of time. Similarly, if Greenwich time is known and the local time is required, we can, being aware of the longitude, subtract the same amount of time for places west of Greenwich and add it for places of east longitude.

But these facts are most useful in enabling a navigator **to determine the longitude** of his position. If the mariner has with him an accurate chronometer keeping Greenwich time, that is, one which records 12 o'clock when the sun is on the meridian of Greenwich, he can, by noting the time at which the sun crosses the meridian (which happens at 12 o'clock noon local time), tell the difference between local and Greenwich time. If the local time is slow compared with Greenwich time his longitude is west, and equal to a number of degrees obtained by reckoning one degree for every four minutes it is slow. If the local time is fast, he is in east longitude, and on the meridian which is found by dividing in the same way the amount of time he is fast.

The zone or international system of time-reckoning.—In the days when places were not within easy communication with one another, either by rail or telegraph, local time was commonly used. The necessity for a uniform standard became clearly evident when railway time-tables had to be printed. Formerly it was common to see the announcement of railway companies, "London (Greenwich) Time observed at all stations." By the introduction of standard time, order was called out of chaos, though it meant that for places west of the Greenwich meridian time indicated by the sun is after the time indicated by clocks. A still further advance was made when the Greenwich meridian was adopted as the prime meridian for the international system of time-reckoning.

Twenty-four standard meridians are now recognised, beginning with Greenwich, and counting toward the east. The time of each of these meridians is thus one hour behind that of the next meridian to the east of it, and one hour in advance of the next meridian to the west. Each meridian may be regarded as the mid-line of a zone 15° of longitude in width, so that the 24 meridians give

the standard times on the international system for the whole world. It is usual for places within half an hour of the standard meridian to adopt the time of that meridian as its mean time, but in some cases the line midway between two consecutive meridians of the 24 hour system is taken as the standard meridian.

The subjoined table, from *Whitaker's Almanac*, shows the countries in which this system of standard time, with the prime meridian at Greenwich, has been adopted:

COUNTRY.	Central Meridian.	Fast or Slow on Greenwich Time.
Mid-Europe	15° E.	1h. fast.
East Europe, British S. Africa, Egypt	30° E.	2h. fast.
Mauritius and Dependencies	60° E.	4h. fast.
Chagos Archipelago	75° E.	5h. fast.
India	82½° E.	5½h. fast.
Calcutta	90° E.	6h. fast.
Burma	97½° E.	6½h. fast.
Hong Kong, Borneo, West Australia	120° E.	8h. fast.
Japan	135° E.	9h. fast.
South Australia	142½° E.	9½h. fast.
Victoria, New South Wales, Queensland, Tasmania	150° E.	10h. fast.
New Zealand	172½° E.	11½h. fast.
Iceland	15° W.	1h. slow.
America:		
Atlantic	60° W.	4h. slow.
Eastern	75° W.	5h. slow.
Central	90° W.	6h. slow.
Mountain	105° W.	7h. slow.
Pacific	120° W.	8h. slow.

Greenwich time is used in France, Spain, Portugal, Belgium, Holland, Gibraltar, and Faröe (Sheep Islands).

Sundials.--Though the time of day, as indicated by the sun, can be estimated approximately by noticing the direction of the shadow of an upright object, a properly constructed sundial is necessary if apparent solar time is to be shown accurately. The face of a sundial, upon which the hours are marked, is the **dial**; and the rod, the shadow of which falls upon the dial when the

sun is shining, is the **style** (Fig. 54). The dial of a sundial is usually either horizontal, or vertical and facing south. It may, however, be inclined at any angle and face any direction, provided that **the style lies parallel to the direction of the earth's axis.** The line showing the hour of twelve noon on the dial must also lie in the plane of the meridian of the place in which the sundial is fixed.

FIG. 54.—Style and dial of a horizontal sundial.

As the altitude of the pole depends upon the latitude, the inclination of the style with regard to the horizon must also vary. For a horizontal dial, the style must be inclined to the dial at an angle equal to the latitude of the place. But whether the dial be vertical, horizontal, or inclined at any angle, or whether it faces north, south, west or east, the style should be parallel to the earth's axis.

A sundial which has the style parallel to the earth's axis, and a dial parallel to the plane of the equator, represents the simplest condition of things. Such a dial may be divided into 24 equal parts by lines drawn from the centre to the circumference, and the shadow will pass from one line to the next every hour. This would be the kind of sundial to use at the poles, where a vertical rod is parallel to the earth's axis and a horizontal board is parallel to the plane of the equator.

A sundial in any latitude could, of course, be arranged with the dial parallel to the equator, and the style in the direction of the earth's axis, and in this case the hours would be separated by equal intervals. It is, however, more convenient to use a horizontal or vertical dial.

Construction of sundials for any latitude.—At the poles a vertical rod lies in the same direction as the earth's axis, and a horizontal circle is parallel to the equator. As the earth turns on its axis at a uniform rate, the apparent daily motion is also uniform, and the shadow on a horizontal dial changes its position at the uniform rate of 15° per hour.

If 24 meridians of longitude are considered to be drawn upon a terrestrial globe, then, in consequence of the earth's rotation, the sun passes from one meridian to the next (that is, through 15° of longitude) every hour. Imagine the earth to be transparent,

like glass, and these meridians to be metal wires upon it. Imagine also, that the earth's axis, instead of being a mere name, consists of a steel rod running from pole to pole, like a knitting needle through an orange. To an observer at the poles of this glass globe, the meridians could be regarded as the lines on the dial of a sundial, while the shadow of a prolongation of the axis could be regarded as the shadow of the style.

Bearing these assumptions in mind, it is easy to understand the principle on which the dial of a sundial is divided for any latitude. The meridians in Fig. 55 represent the hours of the day. A plane parallel to the horizon of the selected latitude is drawn through the earth's centre, at its proper inclination to the equator, the inclination in the diagram being that of the horizon of a place in the latitude of Edinburgh. Lines are drawn from the points of intersection of this plane with the hour lines (meridians), to the centre of the plane, and are marked with the corresponding numbers. The divisions thus obtained represent the hours on a horizontal sundial for the place chosen. A practical application of the principle is shown in Fig. 50.

FIG. 55.—To illustrate the principle upon which sundials are graduated.

Mean solar day.—Equation of time.—A day, as measured by the sundial, that is, the interval between two successive southings of the sun, varies in length throughout the year, and it is not difficult to understand that such a variable day cannot form a convenient standard of time. But if the lengths of all the days in the year are added together, and the length of a year thus measured by the sun is divided by the number of days in the year, we obtain an interval of time which is always the same. Such a day, which is, of course, an imaginary one, is called a **mean solar day**. Sometimes the mean solar day is longer than the day measured by the sundial, sometimes it is shorter, and occasionally both days are of exactly the same length. Sundial

time is known as **apparent time**, and clock time as **mean time.** The amount of time which must be subtracted from, or added to the time shown by the sundial, in order to obtain mean solar time, is called the **equation of time.** Its value for every day in the year is given in the *Nautical Almanac* and other publications. All clocks and watches keep mean solar time, and consequently there is usually a difference between the time recorded by the sundial and that given by a correct clock.

Comparison of different days.—It will be well to compare carefully the various sorts of days, to see in what respects they resemble one another and in what they differ.

A **solar day** is the interval of time between two successive southings of the sun. It is a day of variable length.

A **mean solar day** is a day of the average length of all the solar days in a year; and it is divided into 24 hours. It differs from the solar day by an interval of time called the *equation of time*, which may amount to as much as about + 15 or − 15 minutes.

A **sidereal day** represents the time which elapses between two successive southings of the same star. It is always of the same length, viz. 23 h. 56 m. 4 secs. of mean solar time.

Apparent solar time (or sundial time) agrees with mean or clock time on April 15, June 15, August 31 and December 24.

EXERCISES ON CHAPTER IV.

1. Find the latitude and longitude of a place which is 1000 miles east of Greenwich and 500 miles north of the Equator. (C.P.)

2. What is longitude, and how does it affect time? What would be the local time and day in Japan (time of 145° E.) and Jamaica (time of 75° W.) corresponding to Greenwich mean time 6 p.m. Monday? (C.J.)

3. Explain what is meant by saying

(*a*) Naples and Prague have the same longitude.
(*b*) Birmingham and Berlin have the same latitude.
(*c*) The time at Dublin is 25 minutes slow by Greenwich.

4. At three places in England the sun rises at the clock times undermentioned:

	A.	Greenwich.	C.
On 20th March, -	6.29	6.7	6.15
On 21st June, -	4.18	3.45	3.29

State how A and C lie with respect to Greenwich in latitude and longitude, and give the direction, if you cannot give the amount, of difference. (C.J.)

5. Irish time is about 30 minutes slow by standard time in Great Britain. Explain fully the meaning of this statement. (O.J.)

6. What is meant by the latitude of a place? Give an account of a simple way of finding the latitude of your school (*a*) on March 21 if it is sunny, and (*b*) on any clear night. (L.J.S.)

7. Explain why the length of a degree of latitude is nearly the same in all latitudes, while that of a degree of longitude diminishes as latitude increases. (O.J.)

8. Find the approximate distance in miles between two places, one in 40° N. latitude and 3° E. longitude, and the other in 50° S. latitude and 150° W. longitude. (C.P.)

9. Show, with the help of a diagram, how to find the pole star. How can the latitude of a place be found from observations of the pole star? (C.S.)

10. Compare the length of a degree of latitude with the length of a degree of longitude: (*a*) at the equator, (*b*) near the poles, (*c*) half-way between the equator and the poles. (C.S.)

11. Calculate and explain the difference in longitude between two places whose local time differs by one hour. If the longitude of Cape Cod is 70° W., find the local time there when it is noon at Greenwich. Why is there no local time at the poles? (Cert.)

12. State concisely the proofs of the earth's rotundity. (Cert.)

13. The Ural mountains are 60 degrees east of Greenwich, and Lisbon is 9 degrees west of Greenwich. What time is it at Lisbon when it is 1 p.m. on the Ural mountains? Show how you arrive at your answer. (Cert.)

14. State what you know of the form and size of the earth. How can the former be demonstrated? (C.J.)

15. When it is 12 noon at Greenwich, what is the time at San Francisco (long. 122½° W.)? Also find what time it will be at Greenwich if 4.30 p.m. at Calcutta (long. 88½° E.).

16. Explain what is meant by longitude.

If you were on a cycling tour on the west coast of Wales you would find that your lighting-up time would be about 15 minutes later than that for London. How do you account for this?

If the lighting-up time for London on a certain day is 8 p.m., what do you think that at Bristol would be?

17. Explain fully why time varies according to longitude. Given that the longitude of Canton is 114° E., Bagdad 44½° E., and Bombay 73° E., find the time at each of these towns when it is midday at Greenwich.

18. When it is 2 a.m. on Thursday at Greenwich it is 9 p.m. on Wednesday at Ottawa and noon on Thursday at Sydney. Calculate the longitude of these places. (C.J.)

19. What do you understand (*a*) by the sun crossing the meridian, (*b*) by Greenwich time?

A man travelling from London to Berlin notices on his arrival that there is a difference of one hour between his watch and German time. How is this?

The longitude of Bombay is 72° 50′ E., of Charleston 80° 40′ W. What time is it at each of these places when it is noon at Greenwich? (C.S.C.)

20. What time is it in Chicago and in Calcutta when it is midday in London (Greenwich)? Give the explanation of this in language simple enough, and with a setting vivid enough, for a child of ten to understand. (A series of lessons is not asked.) (N.F.U.)

CHAPTER V.

THE EARTH AS A PLANET (*Continued*).

12. THE REVOLUTION OF THE EARTH.

1. Measurement of sun's noonday altitude. (*Outdoor work.*)—Fix a thin rod upright in a drawing-board, or suitable piece of wood. Draw a line upon the wood passing through the point in which the rod is fixed. Place the board out of doors, so that it is horizontal

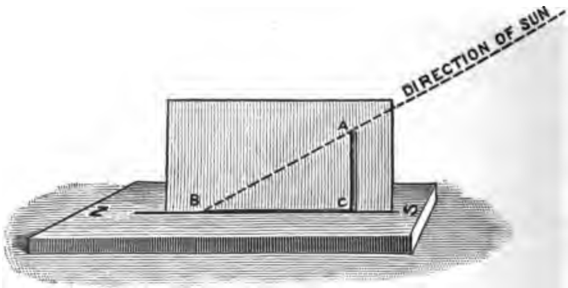


FIG. 56.—Method of measuring roughly the altitude of the sun at noon.

and the line upon it lies due north and south. (If the true north and south direction is not known, it should be found as described in Chap. I.) When the shadow of the rod falls upon the line, that is, at noon, mark upon the board the point where the end of the shadow touches the line. Stand a piece of cardboard upright upon the north and south line, and mark upon it three points (i) at the bottom of the rod, *C* (Fig. 56); (ii) at the top of the rod, *A*; (iii) at the point reached by the end of the shadow, *B*. Connect these points and measure the angles *ABC* and *BAC* with a protractor. The angle *ABC* shows the altitude of the sun at noon on the day of the

observation, while the angle BAC shows its angular distance from the zenith. On March 21 and Sep. 23, notice that the latter angle is the same as the latitude of your position. On June 21 it is equal to $23\frac{1}{2}°$ less than your latitude, and the sun's altitude is therefore $23\frac{1}{2}°$ greater than on March 21 or Sep. 23. On December 21 the angle BAC is $23\frac{1}{2}°$ greater than your latitude, and the sun's altitude is therefore $23\frac{1}{2}°$ less than on March 21 and Sep. 23.

Explain how, on any of these dates, an explorer could determine the latitude of his position, provided that he could see the sun at midday.

2. Conditions for a constant noonday altitude.—Place a lighted lamp upon a table, and near it a small globe, or a tennis ball with a knitting needle through its centre, forming an axis. Arrange the globe, or ball, with the axis perpendicular to the table, as in Fig. 57, and the equator on a level with the light of the lamp. Carry the globe around the lamp on this level, and notice

(*a*) that the light, which represents the sun, is directly overhead at the equator in every position of the globe;

(*b*) that the direction, with reference to the zenith or to the horizon, of a line from the light to any place at noon (that is, when the place directly faces the light) depends upon the latitude, and is constant for any one latitude;

(*c*) that during a complete spin of the globe every place faces the light for half the period of spin, and is in the dark for the other half.

The model thus illustrates that, *if the earth revolved round the sun with its axis perpendicular to the plane of its orbit* (called the plane of the ecliptic), the sun would always have the same altitude at noon at any one place, and this altitude would depend upon the latitude of the place. Also, that day and night would be of equal length everywhere throughout the year.

3. Explanation of inclination of equator to ecliptic.—Incline the axis of the globe, or ball, about $23\frac{1}{2}°$ out of the vertical, or $66\frac{1}{2}°$ from the level of the table. Place the globe in the four positions represented in Fig. 57, the axis being kept pointing in a constant direction. Notice that

(*a*) at our midsummer (summer solstice) the light is directly overhead in latitude $23\frac{1}{2}°$ north of the equator (Tropic of Cancer);

(*b*) at our midwinter (winter solstice) the light is directly overhead in latitude $23\frac{1}{2}°$ south of the equator (Tropic of Capricorn);

(*c*) at two positions in spring and autumn respectively, known as the equinoxes, the light is directly over the equator.

Carry the globe completely round the lamp to represent the earth's annual revolution round the sun.

Notice that, on account of the inclination of the axis, the sun's apparent position, seen from the equator, varies gradually from lat. $23\frac{1}{2}°$ north to lat. $23\frac{1}{2}°$ south. At places on the earth, between lat. $23\frac{1}{2}°$ north and lat. $23\frac{1}{2}°$ south of the equator, the sun is directly overhead at noon twice in the course of a revolution.

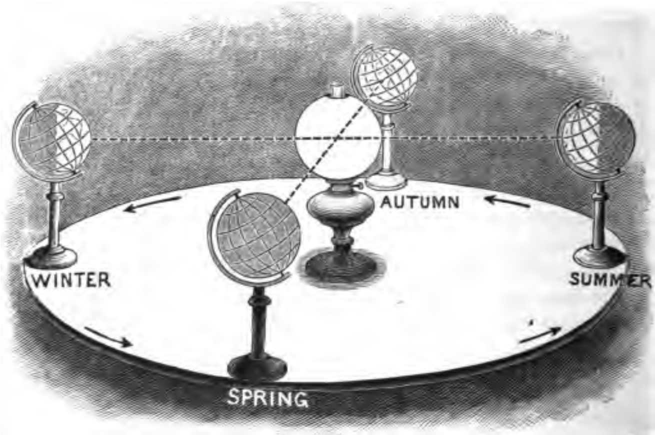


FIG. 57.—To explain how the annual changes of the sun's noonday altitude are produced by the inclination of the earth's equator to the plane of the ecliptic.

4. Explanation of variation of sun's noonday altitude.—In the position of London, stick a long pin into the globe, pointing to its centre. The other end of the pin will point to the zenith of London. Place the globe successively in the four positions of the equinoxes and solstices as before, and in each case arrange the globe to make the pin face the light, so as to represent the position of London at noon. Notice that

(*a*) at the summer solstice the direction in which the light is seen at noon is not far from the zenith (this represents the high sun of summer);

(*b*) at the winter solstice, the light is seen much nearer the horizon, or further from the zenith, of London than in summer;

(*c*) at the equinoxes, the light at noon is seen in a direction midway between the extreme points of summer and winter.

The annual variations of the sun's noonday altitude at any place

can be explained similarly by the inclination of the earth's equator, or axis, to the plane of the ecliptic, that is, to the plane of revolution around the sun.

5. Experiment illustrating variation in the length of day and night.—(*a*) Place the globe in the position for the *spring equinox*, and spin it in this position to represent the diurnal rotation of the earth. Notice that every part of the earth is turned towards the light during half of a complete rotation (half a solar day) and away from it during the other half.

(*b*) Place the globe in the position for our *midsummer day* (sun $23\frac{1}{2}°$ north of equator) and spin it. Notice that

(i) every place in the northern hemisphere is longer in illumination than in darkness;

(ii) the north polar regions are not turned away from the light at all during the rotation of the globe;

(iii) the south polar regions are in darkness throughout the rotation.

(*c*) Place the globe in the position for our *midwinter day* (sun $23\frac{1}{2}°$ south of the equator) and notice that

(i) places in the northern hemisphere are in darkness longer than in illumination during a spin of the globe;

(ii) the south polar regions are in illumination during the complete rotation;

(iii) the north polar regions are in darkness throughout a rotation.

6. Sunlight and the earth.—(*a*) With soft wax fix a drawing-pin at the position of England on a terrestrial globe with the stalk pointing upward. Arrange the globe so that the drawing-pin is directed to the zenith, that is, is vertical, and the globe is in a position where the sun can shine upon it. When a globe is so arranged, half of it will be seen to be illuminated by the sun and half to be in darkness. At whatever time of day or year the observation is made, the actual part of the earth lit up by the sun is exactly that seen to be illuminated on the globe.

(*b*) Keeping the globe in the same position as in (*a*), fix a drawing-pin in a narrow strip of cardboard, and move the strip about on the globe, stalk upwards, until the stalk of the pin has no shadow. The part of the globe under the pin is the place on the earth where the sun is in the zenith at that instant. The position of the pin shows also the distance of the sun north or south of the equator on the day of observation.

7. Estimation of length of day at different latitudes and seasons.—(*a*) Notice that in any position of the globe:

(i) the fraction of any circle of latitude which is illuminated is equal to the fraction of a day during which places on that latitude enjoy daylight;

(ii) that the centre of the illuminated hemispherical surface is a point which has the sun in its zenith.

(*b*) Open out a pair of compasses until when one point is on the equator of your globe the other point just reaches the pole. Notice

(i) that a circle of this radius, described from a point on the equator as centre, cuts each circle of latitude into two equal parts, indicating that when the sun is overhead at the equator, day and night are equal all over the earth;

(ii) that a circle of this radius, described from a centre on the Tropic of Cancer, (α) includes all places between the north pole and lat. 66½° N., (β) excludes all places between the south pole and lat. 66½° S.; and (γ) cuts all other lines of latitude except the equator into unequal parts representing in each case the proportion of daylight and darkness at that latitude on our midsummer day;

(iii) that a circle of this radius described from a centre on the Tropic of Capricorn (α) includes all places between the south pole and lat. 66½° S., (β) excludes all places between the north pole and lat. 66½° N., and (γ) cuts all other lines of latitude except the equator into unequal parts representing in each case the proportion of daylight and darkness at that latitude on our midwinter day;

(iv) that these and all other great circles bisect the equator, indicating that at the equator day and night are equal throughout the year.

(*c*) Using a globe and compasses, determine in this manner the number of hours of daylight enjoyed per day by places on latitude 60° N. at dates when the sun is overhead at latitudes 5° N., 10° S., 15° N., 20° S. respectively.

(*d*) Referring to the table given on p. 95, estimate the number of hours of daylight at (i) London, (ii) Melbourne, (iii) Quito, (iv) North Cape, Iceland, on the first day of each month of the year.

Revolution of the earth round the sun.—The earth, in addition to its regular rotation upon its axis, has another motion which carries it round the sun on a fixed path, called its **orbit**, once a year. The earth's orbit is an ellipse, differing little in form from a circle. Imagine a plane passing through the centre of the earth and the centre of the sun, such that the earth's centre will fall in this plane at all times of the year, that is, whatever the position

of the earth on its orbit may be. This plane, containing the earth's orbit, is called the **plane of the ecliptic.**

Or, to put the same fact in another way, the earth and sun may be imagined as floating in a boundless ocean, both of them being half immersed, or sunk as far as their centres. In these circumstances the surface of such an ocean would be the plane of the ecliptic. The earth must be supposed to float in such a manner that its axis makes an angle of $66\frac{1}{2}°$ with the surface of the ocean, because the axis of the earth is inclined at an angle of $66\frac{1}{2}°$ to the plane of the ecliptic. The plane containing the earth's equator is known as the plane of the equator, and from

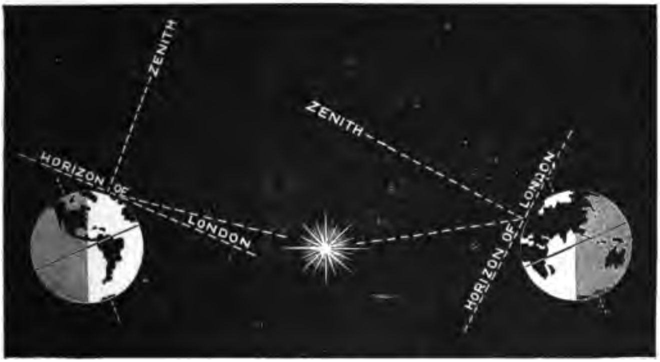


FIG. 58.—To explain the differences of altitude of the sun in summer and winter, as observed from London.

the inclination of the earth's axis it follows that **the plane of the equator and the plane of the ecliptic are inclined to one another at an angle of $23\frac{1}{2}°$.**

Some consequences of the inclination of the earth's axis.—The earth's axis, whatever its position on its orbit, is inclined at the same angle always. Or, at the various positions of the earth in its annual journey round the sun the directions of the axis always remain parallel to one another. The axis always seems to point in the same direction in space, and near that point in the sky at which the pole star is seen.

It is due to this inclination of the earth's axis that the midday sun has a different altitude at different times of the year. Fig. 58

shows the positions of the earth at midwinter and midsummer respectively in the northern hemisphere. At our midwinter, when the earth is in the left-hand position of Fig. 58, the north pole of the earth's axis points away from the sun. It is clear that to an observer in London the sun will appear very near the horizon. When, six months later, the earth has reached the right-hand position of Fig. 58, the north pole of the axis points towards the sun, and the observer in London will now see the sun much nearer the zenith than when the earth was in its midwinter position.

Annual variation of the sun's midday altitude.—The daily variations in the length of the shadow of a fixed object, as the sun describes its daily apparent path in the sky, has been described already. The noonday shadow is the shortest shadow for the day, but the observations of this shortest shadow, day by day, will show that its length varies throughout the year. In summer, the noonday shadow is comparatively short, and from midsummer to midwinter it gradually lengthens, while from midwinter to midsummer it gets shorter and shorter day by day.

It has been seen in Expt. **12**, 1 that the length of a noonday shadow affords a means of finding the **altitude**, or angular distance above the horizon, of the sun at noon; the angle of altitude subtracted from 90° naturally gives the sun's angular distance from the zenith. *The angle between the celestial equator and the zenith of any place is equal to the latitude of that place.* Twice a year—on March 21 and September 23—the sun is on the celestial equator, and it follows that on these two dates the noonday sun is in the zenith of an observer on the equator. On these dates also the angle between the noonday sun and the zenith is equal to the latitude of the place of observation. On June 21, an observer in the northern hemisphere sees the noonday sun at an angular distance from the zenith which is equal to his latitude *minus* 23½°; on this date, therefore, the noonday sun is in the zenith of places of latitude 23½° N., *i.e.* of places on the Tropic of Cancer. On December 21, an observer in the northern hemisphere sees the noonday sun at an angular distance from the zenith which is equal to his latitude *plus* 23½°; and on this date the noonday sun is in the zenith of places of latitude 23½° S., *i.e.* of places on the Tropic of Capricorn.

The following table shows at what latitudes the noonday sun is in the zenith from month to month:

DATE.	Latitude along which noonday sun is in the zenith.	DATE.	Latitude along which noonday sun is in the zenith.
January 1 -	23° S.	July 1 - -	23° N.
February 1 -	17° S.	August 1 -	18° N.
March 1 -	7° S.	September 1 -	8° N.
March 21 -	**0°**	**September 23** -	**0°**
April 1 - -	5° N.	October 1 -	3° S.
May 1 - -	15° N.	November 1 -	14° S.
June 1 - -	22° N.	December 1 -	22° S.
June 21 - -	**23½°** N.	**December 21** -	**23½°** S.

Variation in length of days and nights throughout the year.—Fig. 59 shows the earth in four positions on its orbit, and the student will recognise the left and right-hand positions as those of midwinter and midsummer respectively. Let us begin with the first of these, and refer only to the northern hemisphere, remembering that it is necessary to reverse this order to know the changes which occur south of the equator. In whatever position the earth may be, one-half of it will be illuminated always; and were the axis of the earth perpendicular to the plane of the ecliptic the day and night would be just twelve hours long always. Supposing the earth in its midwinter position, we must think of it as continually spinning round upon its axis, and imagine ourselves on some middle parallel of latitude, say, at London. The latitude, *i.e.* the distance north of the equator, remains the same, and hence during a complete rotation a circle is described round the earth parallel to the equator. Now, if such a latitude circle be imagined round the earth when it is in this left-hand position, it is clear that a larger part of the latitude circle will be in the dark than will be in the light. This is the same as saying that the observer is in the dark for a longer time than he is in the light, or for him the nights are longer than the days. Further, the length of daylight and darkness will be respectively proportional to the fractions of the circle which are

lit up and the reverse. In this position the north pole, and all places within $23\frac{1}{2}°$ from it, never come into the light, so that places within the circle called the **Arctic circle** have a continuous night. It also follows that between the Arctic and Antarctic circles sunrise is latest and sunset earliest in the most northerly latitudes.

When, six months later, the observer at London has been carried with the earth to the right-hand position in Fig. 59, the greater part of a latitude circle, representing his path as the earth rotates, will be in the light, or for him the days will be longer

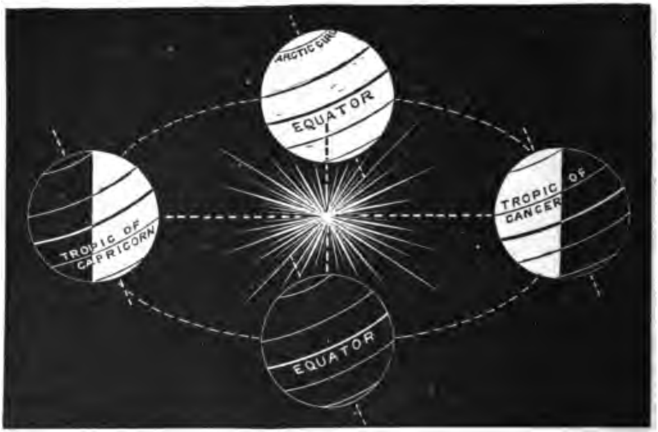


FIG. 59.—The earth in its orbit at the equinoxes and solstices.

than the nights. At this time places within the Arctic circle never get out of reach of the sun's rays, or for its inhabitants there is continuous day; while between the Arctic and Antarctic circles, sunrise is earliest and sunset latest in places having the most northerly latitudes. This is the explanation of the familiar fact that the days are longer in summer and shorter in winter in Scotland than in England.

The equinoxes.—At the two places on the top and bottom of Fig. 59, midway between the extreme positions described, just one-half of the circle marked out by the observer during a single spin of the earth is in the light, and just one-half in the dark. That is, in these two positions the days and nights are exactly

equal in length. These positions are called **equinoxes.** One, when the earth is on its way towards midsummer, is called the **spring** or **vernal equinox**, and occurs on March 21st. The other, when the earth approaches winter, is the **autumnal equinox**, which falls on September 23rd.

Sunrise and sunset.—Fig. 59 illustrates the varying direction of the sun's rising and setting at different times of the year. If we imagine ourselves at the intersection of a meridian and a parallel of latitude, and bear in mind that the meridian runs north and south and the parallel east and west, we shall understand readily why, at the moment when the rotation of the earth is carrying our position from light into darkness in summer, the sun must appear to the north of west. Similarly, on the other side of the globe representing summer, from a position emerging from darkness into light the sun will appear to the north of east. On the other hand, in winter the conditions will be exactly reversed, the rising sun being seen to the south of east and the setting sun to the south of west. Half way between these extreme positions, that is, at the equinoxes, the sun will naturally rise exactly in the east and set exactly in the west.

The seasons.—The alternation of the seasons is also the outcome of the inclination of the earth's axis. During the day our planet is receiving heat from the sun continually, which it radiates into space during the night. Now, *if the days are longer than the nights*, it is evident that, in the absence of other disturbing circumstances (see Chapter XII.), more heat is received during the hours of light than is radiated throughout the night, or *there is a net gain of heat.* Whereas, if the opposite holds true, and the nights are longer, there is a *net loss of heat.*

Reference to Fig. 59 shows that, as the earth moves round its orbit in the opposite direction to the hands of a watch, from its midwinter position through the spring equinox towards midsummer there is a gradual increase in the lengths of the days and consequently a net gain of heat, and *the northern hemisphere gets warmer and warmer*; while after the midsummer position has been passed and the earth is moving on through the autumnal equinox towards midwinter again there is a net loss of heat and *the northern hemisphere becomes gradually colder.*

Illumination of a fixed globe.—Though the earth rotates on its axis and revolves around the sun, thus causing day and night and the seasonal changes which have been described, yet precisely the same effects would be produced if the earth were fixed and the sun revolved around it in the plane of the ecliptic once a day. When a terrestrial globe is fixed so that its axis is parallel to the earth's axis and the meridian of the place of observation faces due south, as in Fig. 60,* then, however the sun shines upon it, the hemisphere of the real earth illuminated at the same time is exactly the same as on the globe. Such a globe enables the declination of the sun to be determined on any day when the sun is shining; for the point on the globe where an upright pin has no shadow gives directly the position of the sun with reference to the equator. By dividing the equator into twenty-four parts to represent hours, or meridian lines, the globe can be used as a sundial. A movable half-meridian is turned until it is under the sun; its shadow on the equator then shows the apparent time.

FIG. 60.—Gregory's sundial globe.

13. THE MOON AND ECLIPSES.

1. Phases of the moon.—Find the time of New Moon from a calendar. Observe the crescent moon, about the time of sunset, two or three nights later. Notice that the horns of the crescent moon are always directed *away* from the Sun. When you think it is Half Moon, reckon the number of days that have elapsed since New Moon. In a similar way, find the number of days from Half Moon to Full Moon, from Full Moon to Last Quarter, and from Last Quarter to New Moon. The shape of the moon should be drawn from week to week in connection with these observations.

* This form of sundial globe, made in pottery so that it can be set up in the open air, was devised by Prof. R. A. Gregory, and is sold by Messrs. Newton & Co., 3 Fleet Street, E.C.

2. Explanation of phases of the moon and related phenomena.—(*a*) Place a lighted lamp upon a table, and a globe at a short distance from it; these represent respectively the sun and earth. Obtain a small white ball—about one-quarter the diameter of the globe—to represent the moon. Carry the ball around the globe as indicated in Fig. 61, and notice that though a hemisphere of the ball is illuminated always, the amount of illuminated surface visible from the globe depends upon the relative positions of the lamp, globe and ball. Show in this way the relative positions of the three bodies, at the times of (i) New Moon, (ii) Half Moon, (iii) Full Moon, (iv) Half Moon again.

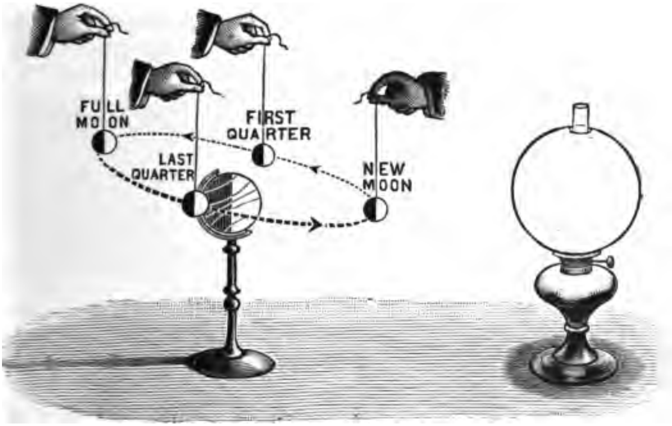


FIG. 61.—Experiment to illustrate the cause of phases of the moon.

(*b*) Notice that when the ball is between the globe and lamp only the dark side is turned towards the globe. This represents the condition for the astronomical New Moon. Move the ball a little in the direction indicated, and a crescent of light can be seen from the globe, just as the crescent moon becomes visible a few days after New Moon.

3. Movements of the moon with reference to the fixed stars.—(*a*) Notice the position of the moon on any night. Repeat the observation several nights in succession at the same hour. Observe that every night the moon is further east at the same hour than it was the night before. Notice that, on account of this, the position of the moon with reference to the sun and stars constantly changes.

(*b*) Fix a simple theodolite or pointer so that a sight can be taken due south. Observe, on several nights in succession, the times at

which the moon appears due south. The time of transit (p. 79) will be found to be about 50 minutes later every night. The times of rising and setting may be expected to be correspondingly belated. Test this surmise by means of the times of rising or setting of the moon given in an almanac. In which phases (Fig. 62) does the moon respectively rise and set in daylight?

4. Explanation of eastward motion of moon.—Place the lamp, ball, and globe upon the table as in Expt. **13**, 2. Imagine objects and marks upon the walls, floor, and ceiling of the room, to represent stars. Carry the ball around the globe to represent the monthly revolution of the moon around the earth. An observer on the globe would see the ball projected upon different objects during the revolution of the ball in its orbit. In a similar way, the moon is seen projected upon different parts of the celestial sphere on account of its movement around the earth. Unlike the eastward motion of the sun, which is only an *apparent* motion due to the real movement of the earth, the eastward motion of the moon is a *real* motion due to its actual revolution.

5. To illustrate eclipses of the moon.—(*a*) Cast a shadow of a sphere on to a screen, using a small source of light, such as a candle-flame. Notice that the shadow is circular and of equal darkness throughout.

(*b*) Substitute a lamp, with a ground glass globe larger than the sphere, for the candle. Notice that the shadow on the screen is made up of two parts, an inner very dark circular patch called the *umbra*, while concentrically arranged round it is a partially illuminated shadow, forming a ring, called the *penumbra*.

6. To illustrate an eclipse of the sun.—Using the lamp with a large globe, cast a shadow of a very small sphere. Notice that the shadow comes to a point, as can be shown by moving the screen slowly from the sphere, when the shadow gradually becomes smaller and disappears. This is a *converging* shadow, while those of the two previous experiments are *diverging* shadows.

The moon is a smaller body than the earth, revolving round it thirteen times during one revolution of the earth round the sun. Like the planet upon which it attends as a **satellite**, it has besides this motion of revolution one of rotation as well. It completes a single rotation in exactly the period of time during which it travels once round the earth. The result is that one side of the moon is never seen from the earth.

At the time when the moon appears largest, which is called **full moon**, it would seem to be the greatest of the heavenly bodies.

This is not by any means actually so, the appearance being caused by the nearness of the moon to the earth. It is the nearest heavenly body. Its distance from the earth is roughly ten times the circumference of the earth, the actual distance varying between 222,000 miles when the moon is nearest to us, or in **perigee**, and 253,000 miles when it is as far away as it can be, or in **apogee**. The average distance is 239,000 miles. The moon's distance from the earth varies because the orbit in which it travels is elliptical, as in the case of the planets. From the effect of nearness upon the apparent size of a body, the student will not be surprised to learn that the moon has a diameter of only one-quarter that of the earth.

Phases of the moon.—The moon travels round the earth once a month; and the interval of time between two successive full moons is 29½ days. The moon has no light of its own, but the

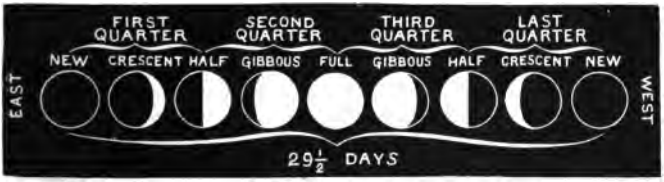


FIG. 62.—Phases of the moon during one lunar month.

sun is shining upon its surface continually, so that the light which the moon appears to possess is really reflected sunlight. We do not, however, always see the whole of the illuminated half of our satellite, and the consequence is that we get the phases or changes of the moon familiar to everyone.

At new moon the illuminated half of the moon is turned away from the earth, so nothing is seen of it. As the moon travels around the earth, first a crescent of the bright surface becomes visible. Day by day it increases in size ("waxes") until full moon is reached, in which case the whole of that part of the moon upon which the sun is shining is seen. From this point the bright face wanes, and eventually the condition of new moon is reached again. Fig. 61 shows how these changes throughout the moon's revolution around the earth may be traced.

The moon's eastward motion in the heavens.—The continual change in the moon's position in the heavens as it revolves round the earth is made clear by noticing, night after night, which stars form its background. The *eastward* motion of our satellite

then becomes very obvious. It is shown, from November 27 to December 7, 1909, by the dotted line in Fig. 63.

Rotation of the moon.—The "man in the moon" always appears to have the same expression; in other words, the same face of the moon is always seen by observers on the earth. This is because the moon rotates on its axis in the same time that it revolves around the earth. When, for instance, the moon has travelled over a quarter of a revolution it has turned on its axis

FIG. 63.—Path of the moon among the stars between November 27 and December 6, 1909.

by a quarter of a rotation and so prevents the observer from seeing the new part of its surface which would, but for this compensating cause, become visible.

Eclipses of the moon.—As was stated in dealing with proofs of the spherical form of the earth, an **eclipse of the moon** is the result of the earth's coming between the sun and the moon (Fig. 65). Eclipses are caused by the fact that light travels in straight lines, producing clearly-defined shadows of objects in its path.

Since the sun is the source of light casting the shadow of the earth into which the moon travels at an eclipse, it is plain that the condition of things represented in Expt. **13**, 5 is taking place on a large scale. The moon first travels into the penumbra and is still visible though her brightness is diminished. When the

umbra is reached, however, the part of the moon within it becomes quite invisible, and it is at this stage that the appearance represented in Fig. 64 where the circular outline of the earth's shadow is seen. Even after the moon has passed entirely into the umbra a dull red disc can still be made out. This is because sunlight is refracted by the earth's atmosphere and so made to strike upon the moon's surface, which reflects it to the earth. The coppery colour is due to the passage of these rays from the sun through the earth's atmosphere.

So far there appears no reason why a lunar eclipse should not occur at every full moon. If the plane in which the moon revolved round the earth were coincident with that in which the earth travelled round the sun, there would be an eclipse at each full

Fig. 64.—Partial and total eclipses of the moon.

moon. But the moon's orbit is inclined to the plane of the ecliptic, and it therefore happens that on some occasions of full moon the earth's satellite is above or below the shadow cast by the earth, and no eclipse occurs. At other times the moon partially passes through the umbra and what is known as a **partial eclipse** takes place. It is only when the centres of the sun, earth, and moon are in the same line that a total eclipse can occur, and this only happens when the three bodies are in the same straight line at the same time that the moon is at the points—called **nodes**—where the moon's orbit cuts that of the earth.

Eclipses of the sun.—These **solar eclipses** occur when the moon comes between the sun and the earth, that is, at new moon (Fig. 66). Expt. **13**, 6 represents the formation of a solar eclipse. The sun casts a shadow of the much smaller moon, and the shadow sometimes falls upon the earth. But evidently the shadow

will only extend over a small part of the earth's surface; that is to say, the eclipse of the sun will not be visible everywhere upon the earth, but only at certain places where the moon is in the line between the observer and the sun.

The moon is sometimes nearer the earth than at others. **Total** solar eclipses, when the sun is blotted out entirely by the moon, occur when the moon is in perigee (nearest point to the earth) and at a node at the same time (Fig. 65). If the moon is in

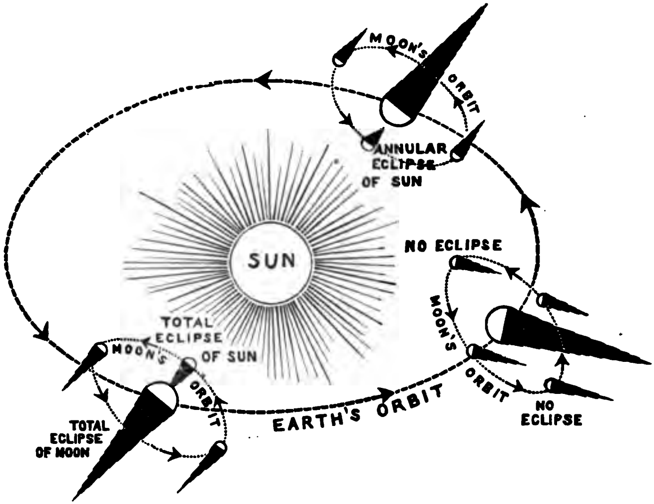


FIG. 65.—To illustrate the inclination of the moon's orbit and the causes of lunar and solar eclipses.

apogee (farthest point from the earth), and at a node at the same time, the shadow cast by the moon does not reach the earth, and consequently the appearance to an observer in the line of the shadow is different. The moon cuts off all the light of the sun except a ring of light surrounding the circle of darkness, and what is called an **annular eclipse** occurs (Fig. 67). Sometimes the moon does not pass in a direct line between the sun and the earth, in which case the sun is covered only partially, as in Fig. 66.

An annular eclipse of the *moon* cannot occur, because, whether the moon is at its nearest or farthest points, the earth's shadow at the point where the moon crosses it has a much greater diameter than the diameter of the moon.

The phenomena observed during a total solar eclipse are very striking. The moon's disc first appears on the western edge of the sun and gradually covers up the whole surface. When the

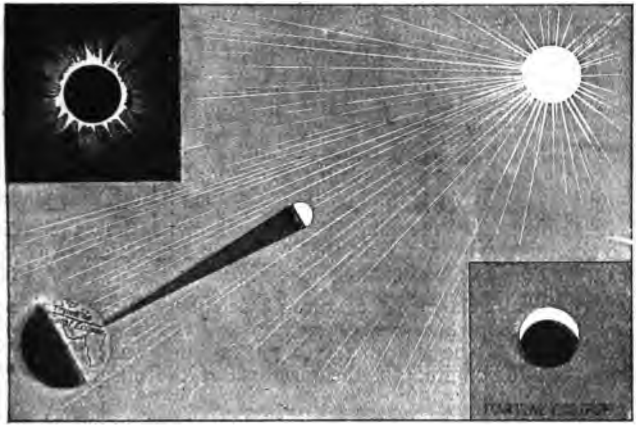


FIG. 66.—An eclipse of the sun. The inset on the left represents a total eclipse, and shows the solar corona; the inset on the right represents a partial eclipse.

sun is obscured totally there is very little light, and the bright stars can be seen as at the beginning of night. Around the sun and extending in luminous sheets and streamers for thousands of miles is seen the **solar corona** (Fig. 66). In addition to this halo, a number of red-coloured "prominences," or solar flames, may be seen shooting out from the sun behind the dark edge of the moon.

FIG. 67.—An annular eclipse of the sun.

These prominences consist chiefly of hydrogen and helium, and it is to investigate them and the solar corona that astronomers send out eclipse expeditions. The phenomena described are only observable during total obscuration of the sun, and as totality only lasts a few minutes, the opportunities to investigate them are utilised to the fullest extent.

EXERCISES ON CHAPTER V.

1. Show how you can estimate the length of the shadow that would be cast by a stick one foot long standing vertically upon a level surface at noon (*a*) on 21st June, (*b*) on 21st December.

2. Explain the reason for the variation in the direction of apparent sunrise with the season, and state the nature of the change. (C.J.)

3. (i) The sun shines throughout the day for three days in each year on the north side of a house. What is, approximately, the latitude of the house? (ii) On a certain day the time of sunset at Greenwich was 7.42 p.m. On the same day at another place in the same latitude it was 7.52 p.m. What is the longitude of this place?

4. (i) Explain the meaning of the statement that the axis of rotation of the earth always points in the same direction. (ii) What is meant by the sun crossing the equator? (C.J.)

5. At a certain place on the 25th of December the sun attained its maximum altitude, which was 14°, at 12.5 p.m. Greenwich mean time. The declination of the sun on the day in question was $23\frac{1}{2}$° S. Find the latitude and longitude of the place where the observations were made. (C.S.)

6. During how much of each year is the sun above the horizon at (i) the North Pole, (ii) London, (iii) Singapore? (C.J.)

7. Explain fully why the sun has greater heating power in the northern hemisphere during July than during December. (O.J.)

8. In summer the sun *rises* earlier and in winter *sets* earlier at Newcastle-upon-Tyne than at Southampton. Explain this. Would it also be true to say that the sun rises earlier on (our) midsummer's day at (*a*) Charleston, S. Carolina (long. 79°·9 W.), than at Havana (long. 82°·4 W.), and at (*b*) North Cape (long. 25°·7 E.) than at Riga (long. 24°·2 E.)?

When it is noon at London, what is approximately the local time at Chicago, Moscow and San Francisco? (Cert.)

9. Poles, of equal length, are fixed in a vertical position at the following places: Calcutta, London, Melbourne, New York, Singapore and Zanzibar. The shadows of the poles are observed at noon on the 21st June and again at noon on the 21st December. Arrange the places mentioned in two columns according to the lengths of the shadows observed (*a*) in June, (*b*) in December. (Prel. Cert.)

10. On 21st June the altitude of the sun at noon is 45°, the direction south. What is the latitude and what would be the altitude at noon on 21st December? (C.J.)

11. You are provided with an upright post, a tape measure, squared paper and a protractor. How would you use these things to determine the sun's altitude at noon, and to draw a north and south line on the ground? (Cert.)

12. Show by sketches the appearance of the moon in (*a*) its first quarter, (*b*) its last quarter. (C.S.)

13. At what times of the year does the sun rise exactly in the east and set exactly in the west? Give reasons for your answer. (O.J.)

14. How are eclipses of the moon caused? Why are they sometimes partial and sometimes total?

15. Explain why sunset is later in summer and earlier in winter in Scotland than in England.

16. Why do the summer days in the northern hemisphere lengthen as we go north, and the winter days shorten?

17. Give a clear explanation of the causes of the changes in the duration of daylight in various latitudes at different seasons of the year. Specially consider latitudes 0°, 30°, 60°, 90°.

18. When the declination of the sun is 10° N., in what latitudes will the noonday shadows, on level ground, be exactly equal in length to the height of the objects casting them? (C.S.)

19. Explain, with diagrams, the path which the sun would appear to take from sunrise to sunset on March 21st (the vernal equinox) to men stationed at Quito (lat. 0°), London, and the North Pole respectively.

How is it that the summit of Mont Blanc is lit up with the sun's rays for some time before Chamonix (at the foot of the mountain) receives any rays at all? (C.S.C.)

20. In what direction is the sun at midday, and where does he rise and set? What changes do you notice in these directions as the year goes on? And what effects are produced by these changes?

How would your answers have to be altered if we were in (1) Iceland, and (2) the Congo district? (C.S.C.)

21. If the moon rises at 6 p.m. to-day, about what time will it rise to-morrow? How can you tell whether a half moon is at its first or its last quarter? (C.S.)

22. How would you set the gnomon or pointer of a sundial? Give your reason. (C.S.)

23. Give approximately the Greenwich time of sunrise and sunset, at the centre at which you are examined, on (*a*) December 21, (*b*) March 21, (*c*) June 21. (C.S.)

24. Explain each of the following: (*a*) How day becomes night, (*b*) how winter becomes summer, (*c*) how two places, not on the same meridian, may have different times at the same moment. (C.P.)

25. Describe in detail the earth's path round the sun, indicating briefly the causes of the seasons and the peculiarities of our calendar. (N.F.U.)

26. Give the reason of unequal days and nights. Show how you could calculate the length of a day in latitude 45° N. on June 21st and on March 22nd. (N.F.U.)

27. Arrange the following places according to the length of the day (*a*) at the end of March, (*b*) at the end of June, putting the place with the longest day first, and carefully explaining your arrangements: Colombo, in Ceylon; Brisbane, in Australia; and Stockholm. (N.F.U.)

28. What facts about the moon could be learnt by carefully watching its appearance and movements each night for a month? Explain the phases of the moon. (N.F.U.)

29. Note briefly the obvious changes to be seen in the moon, as regards both shape and position in the sky, from its first appearance as a crescent until its waning. How long does the whole process take? Do we see the waxing moon rise and the waning moon set? If not, why not? (N.F.U.)

PART II.

LAND AND SEA.

CHAPTER VI.

LAND AND SEA.

14. DISTRIBUTION OF LAND AND WATER.

1. Ratio of land to water.—Examine a school globe and notice the great preponderance of water surface over land surface. Turn the globe so that you can see as much land as possible in one view. Where, approximately, is the centre of the "land hemisphere"? Express the answer both in words and in latitude and longitude.

Turn the globe so that you can see as much water as possible in one view. Where is the centre of the "water hemisphere"? Is it north or south of the equator?

2. The main land masses.—*Using a globe*, (*a*) find and study the positions of the following *continents*: Europe, Asia, Africa, North America, South America, Australia. Arrange them as nearly as possible in the order of their size. (Could you do this from a map of the world on Mercator's projection? See p. 57.)

(*b*) Make a list in order of their size of the six largest *peninsulas* in the world, stating in each case (i) the *isthmus* by which the peninsula is connected with the neighbouring mainland, and (ii) the direction in which the peninsula points. With how many of the peninsulas is an island or a group of islands associated?

(*c*) Make a list, in order of size, of the six largest *islands*.

3. The main bodies of water.—*Using a globe*, (*a*) Find and study the positions of the following *oceans*: Atlantic, Pacific, Arctic and Indian. Arrange them as nearly as possible in order of their size, stating in each case the names and directions of the continents bordering them.

(*b*) Make a list, in order of size, of the six largest *seas* (portions of oceans more or less enclosed by land), state the ocean of which each is a part, and name the *strait* by which it is connected with its ocean.

(*c*) Make a list, in order of size, of the six largest *lakes*.

Ratio of land to water on the surface of the globe.—About 72 per cent. of the whole surface of the globe is covered with water. The actual extent of this vast expanse is estimated variously by different authorities, but for our purpose it will be sufficient to say that it is about 145 millions of square miles out of a total of 197 millions. It is not distributed equally over the

FIG. 68.—The land and water hemispheres.

whole surface of the planet; there is far more land in the northern than in the southern hemisphere. If a globe is arranged so that England is on the top, it is found on looking down upon it that a very large proportion of the hemisphere seen is land, but on examining the lower hemisphere it is found to be almost entirely water. England is situated at just about the central part of the land hemisphere.

The continents.—The main land masses of the earth are called **continents.** It is more scientific to define their margins by the contour line of 600 feet below sea level than, as usual, by the present shore line. *Europe* and *Asia* appear to form one continuous area, but a well-marked depression along the east of the Ural mountains shows that a comparatively slight subsidence would cause them to be separated by water—a fact which justifies the custom of regarding them as distinct continents. *Australasia*

(consisting of Australia with the associated smaller islands) is sometimes regarded as an annexe of Asia to the south-east, although it properly receives continental rank. *Africa* is separated, at present, from Europe by the eastward rift of the Mediterranean Sea; and in the "New World" *North America* and *South America* are almost separated by the Gulf of Mexico and the Caribbean Sea.

The areas of the continents are estimated as follows:

Europe - - -	3,900,000	square	miles;
Asia - - -	17,300,000	"	"
Africa - - -	11,530,000	"	"
North America - -	9,500,000	"	"
South America - -	6,820,000	"	"
Australasia - -	3,450,000	"	"

The great peninsulas.—The separation of North America from South America by the Gulf of Mexico, of Africa from Europe by

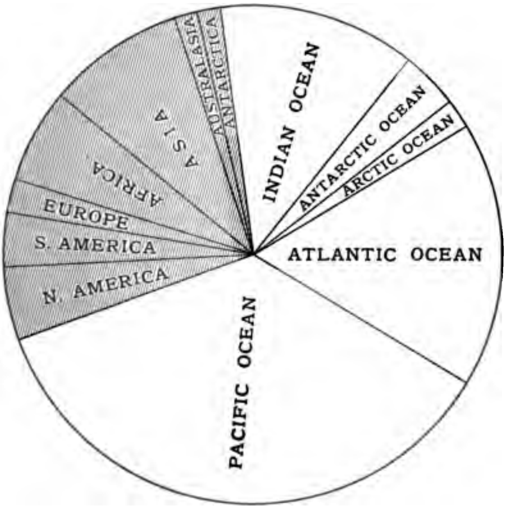


FIG. 69.—Relative areas of continents and oceans.

the Mediterranean Sea, and of Australasia from Asia by the South China Sea, are sometimes regarded as evidence of a great rift

which passes round the world, and at a very early period in the earth's history tore the great continents across to form more or less well-defined northern and southern portions. The Persian Gulf may also be included in this great depression. **South America** is, however, not completely detached from North America; it therefore forms a **peninsula**, the connecting neck of land constituting the **isthmus** of Panama. Similarly **Africa** is a peninsula; it is connected with Asia by the isthmus of Suez. Australasia, on the other hand, is composed of a number of **islands**.

Division into oceans and seas.—For the sake of convenience in locating the position of places on the ocean, geographers have given names indicating the relative size and nature of parts of the waters covering the earth.

There are five main divisions to which the term **ocean** is given, they are, in order of their areas, *Pacific*, *Atlantic*, *Indian*, *Antarctic*, and *Arctic* Oceans.

The **Pacific Ocean** is the portion lying between Asia and Australia on the west, and North and South America on the east. Its area is about 67,700,000 square miles.

The **Atlantic Ocean** is bounded on the west by North and South America, and on the east by Europe and Africa. It has an area of some 34,300,000 square miles.

The **Indian Ocean** is surrounded by land on the west, north and east—Africa on the west, Asia on the north, Polynesia and Australia on the east. It extends in a southerly direction as far as the Antarctic Circle. Its area is approximately 27,700,000 square miles.

The **Antarctic Ocean** is the whole of the extent of water within the Antarctic Circle, the **Arctic Ocean** that within the Arctic Circle.

Portions of these oceans more or less enclosed by land are referred to as **seas**, such as Baltic Sea, Mediterranean Sea, China Sea, etc.

15. THE OUTLINES AND SURFACES OF LAND MASSES.

1. Main directions of coast lines.—Study a map of the world on *Mercator's projection*, which (p. 57) shows shapes, though not sizes, correctly. What are the general directions of the following main lines of coast: (*a*) from Florida to Newfoundland, (*b*) from

South Patagonia to Pernambuco, (*c*) from Cape Colony to Baluchistan, (*d*) from Malacca to Bering Strait?

Make a list of any coast lines which are approximately (i) parallel, (ii) at right angles, to these.

Make a list of all long lines of coast running approximately east and west.

2. Eastward trend of southern land masses.—How do South America, South Africa and Australia lie with respect to North America, North Africa and Asia respectively? Note the positions of any large islands near the south ends of the continents; do they lie to the south-east or to the south-west?

3. Comparative heights of land masses.—Study either an orographical map of the world or orographical maps of the continents in succession. In each continent find and make a note of:

(*a*) the positions and heights of the principal *peaks*;

(*b*) the positions and directions of the chief *mountain ranges*, noticing especially whether they run (i) approximately east and west, (ii) approximately N.E. and S.W. or N.W. and S.E., (iii) roughly parallel or at right angles to the nearest coast line;

(*c*) the position and extent of any *plateaux* (p. 115) and *plains*, with their estimated average heights;

(*d*) the position and extent of any ground lying below sea level.

4. Sections across continents.—From bathy-orographical maps of the continents draw the following sections, in the manner explained on pp. 30 and 37:

(*a*) from Galloway to the Ural Mountains, along latitude 55° N., and from the Arctic Ocean to the North of Africa, along meridian 15° E.;

(*b*) from the Arctic Ocean to the Indian Ocean, along meridian 80° E.;

(*c*) from the Mediterranean to the South Indian Ocean, along meridian 30° E.;

(*d*) from the Pacific to the Atlantic, along latitude 40° N.;

(*e*) from the South Pacific to the South Atlantic, along latitude 20° S.;

(*f*) from New Guinea to Tasmania, along meridian 145° E.

5. Drainage areas of continents.—Taking a map of each continent separately, make a list of the principal rivers flowing into each of the oceans bordering that continent. Tabulate, for example, the European rivers flowing into the Atlantic and Arctic Oceans, the Mediterranean Sea (including the Black Sea) and the Caspian Sea respectively.

Now draw dotted lines on the map to separate the head waters of each group from those of other groups. The dotted lines are *watersheds*, and the areas into which they divide the continent may be called the *drainage areas* of the continent.

Do the same with the other continents in turn.

In each case state how far the watersheds coincide with (*a*) mountain ranges, and (*b*) political boundaries.

Directions of coast lines.—An orographical map of the world on Mercator's projection—which (p. 57) represents shapes and directions, though not relative areas, correctly—shows at a glance the main "lines of construction" of the great land masses. Among these features the most striking is perhaps the arrangement of the principal *coast lines* to run in directions approximately north-east and south-west, or at right angles to this, viz. north-west and south-east. Conspicuous among the former group are the east coasts of North and South America, of Africa (with the south coast of Arabia) and of Asia; while in a direction roughly perpendicular to this are the west coasts of North America and Peru, the north coast of South America, the north-east shore of Labrador, the shores of the Red Sea and many smaller stretches.

Another feature which is brought out clearly by such a map is the fact that the southern land masses lie a little further to the east than those with which they are associated most closely on the north. South America lies to the south-east of North America, South Africa to the south-east of North Africa, Australia to the south-east of Asia. The suggestion has indeed been made that these southern lands have been wrenched a little to the east of their original positions.

It is also noticeable that an island, or a group of islands, occurs near the extremity of each of the main southern land masses—a little to the east. Tierra del Fuego is associated in this manner with South America, Madagascar with Africa, Ceylon with India, and Tasmania with Australia. The full significance of these facts is not yet understood, and we need not concern ourselves at present with the explanations which have been suggested.

The heights of the land.—The average height of the continents is estimated at only some 2300 feet above the level of the sea, but

the altitude of the land varies between the 29,000 feet of the highest mountain (Mt. Everest) to an actual depression below sea level in certain places, *e.g.* to the north and west of the Caspian Sea (which is itself 100 feet below sea level), and in Holland as well as in parts of Africa, Australia and North America. The high land forms either elevated table-lands, usually cut up by deep river valleys and called **plateaux** if they slope on all sides to lower levels; or more or less well-marked ridges of the earth's crust, called **mountain chains.**

The principal **plateaux** are:

In *Europe*, the Spanish Plateau.

In *Asia*, the plateaux of Tibet, Mongolia (almost rainless), Iran, Arabia and the Deccan (India).

The greater part of *Africa*, south of the Sahara, consists of the "Great Central Plateau"; in it a great line of fracture can be traced through the great lakes Nyasa, Tanganyika and Victoria Nyanza, through the Plateau of Abyssinia, and up the Red Sea and the Gulf of Akaba through the valley of the Dead Sea.

In *North America* only the high land of Mexico is flattened sufficiently to receive, usually, the name of plateau, and in *South America* only that of Bolivia.

The **mountain ranges** lend themselves more readily to classification. In the *Old World* the mountain chains of the northern continents, for the most part, run east and west; this is exemplified by the Pyrenees, the Alps, Carpathians, Caucasus, Himalayas and Altai Mountains. The Atlas range of North Africa may be included with these. The Pennines, Scandinavian Mountains, Apennines and Ural Mountains, which form an obvious exception to the rule, are now of minor importance, and much older in date of origin (Chap. IX.). In *Africa* and *Australia*, on the other hand, such ranges as are at all well defined run north and south.

In the *New World* the mountain ranges, almost without exception, take a north and south direction. The Rockies and Appalachian Mountains of North America, and the Andes of South America show this conspicuously.

Plains—the more or less flattened lowlands—perhaps occupy a greater area of the land surface of the earth than plateaux and mountain chains together, and the student should remember at

least the positions of the largest expanses. Among these may be mentioned the Great Lowland Plain of Europe; the Great Siberian Plain, and the plains of China, India and Mesopotamia of Asia; the Great Central, the Northern, Gulf and Atlantic Plains of North America; and the Selvas of the Amazon in South America. These areas form on the whole the most fertile part of the earth's surface, and are watered by long, slow and winding rivers, which constitute the principal means of communication, and have in many cases actually laid down the material of the plain, as sediment washed down from the high lands in which they take their source.

It will be understood that the terms plain and plateau are purely relative, and that it is in many cases a matter of opinion whether one word or the other is the more appropriate. Even a mountain can only be defined in relative terms as high land with an insignificant summit area.

Drainage areas of continents.—It is an easy and instructive exercise to trace out the main watersheds of the continents, and so to divide the land into "drainage areas" which show what proportion of it contributes to each of the various adjoining oceans.* Such an exercise shows that watersheds coincide in general with mountain ranges, which have determined many political boundaries. It also emphasises the nature of certain lakes and inland seas which, lying in a depression having no outlet to the sea, and receiving the drainage of the high land surrounding them on all sides, act as evaporating pans, and concentrate the river water to a sort of brine, which increases in strength continually. Such **salt lakes** are naturally found chiefly in areas where scanty rainfall is accompanied by great evaporation. The Great Salt Lake in Utah, the Dead Sea, and the Caspian are well known examples of such lakes, and the **salt deposits** at Salton in the California desert, and in the desert regions of Turkestan, Patagonia, and China, are no doubt to be referred to a similar origin. Also there is evidence that the salt-bearing rocks of Cheshire and Worcestershire were formed under conditions of the same kind.

* It is estimated that 27 per cent. of the rivers of the world drain into the Pacific and Indian Oceans, 22 per cent. have no outlet to the sea, and no less than 51 per cent. are tributary to the Atlantic (Avebury).

16. THE CONTOUR OF THE OCEAN FLOOR.

1. The ocean floors.—*Examine a bathy-orographical map of the world.* (*a*) How many different depths are shown on it? In what parts of the world are there the greatest extents of shallow seas? Where is the sea deepest? Which coast lines would be most affected by an elevation of 600 ft.? What would be the chief changes thus produced? Which coast lines would be least affected?

(*b*) What amounts of elevation of the ocean floor would join (i) the British Isles to Europe, (ii) Greenland to Europe, (iii) Asia to North America, (iv) Australia to Asia, (v) Europe to Africa?

(*c*) From the information supplied by the map write an account of the contour of the floors of the Atlantic, Pacific and Indian Oceans, and draw sections across the Atlantic (i) from Florida to Cape Verde, (ii) from New York to Valentia (Ireland).

(*d*) *The Continental Shelf* is defined as the sea bottom between the shore and the 100-fathom line. Do the British Isles stand on the edge of a continental shelf?

2. The seas of Europe.—*Examine a bathy-orographical map of Europe.* (*a*) How does the land abutting on shallow seas differ in height from that facing deeper seas? Give examples. What is the greatest depth shown on the map?

(*b*) Draw a map of the outline of Europe as it would be if the land rose 600 feet. Where would there be the least alteration in the coast line? Where most? What *rivers*, now separate, would be likely to join together? Where would they reach the sea? What new *lakes* would be formed? What would the present *estuaries* become?

(*c*) Write a description of the topography of Europe as it would be after an elevation of 6000 feet.

(*d*) What would be the principal changes in coast line if Europe were depressed 600 feet? What would then become of such river valleys as those of the Elbe, Rhine, Tagus, Ebro, Rhone and Po? What name would then describe them? Where, in the present coast line of Europe are there signs of "drowned river valleys"?

3. Deposits on the ocean floor.—Compare the maps Figs. 70 and 74, and state as nearly as possible the range of depths at which the deposits mentioned in Fig. 74 occur. Compare the terrigenous (*i.e.* land-derived) deposits with the extent of the continental shelf, and study particularly the distribution of globigerina ooze and red clay in the Atlantic.

Modes of determining depths of the sea.—To find the depth of water in any place where it does not exceed about 1,000 fathoms, all that it is necessary to do is to attach to the end of a line an ordinary *deep-sea lead*, which is a prismatic leaden block, about 2 feet in length, and about 100 lb. in weight, narrowing a little towards the upper end, where a stout iron ring is attached. Before the lead is "heaved," it is armed with a thick coating of tallow at its lower extremity, which is hollowed out slightly for the purpose. The line is allowed to run out until the bottom is felt, and the length of it which has been paid out is measured by means of differently coloured strips of bunting tied on to the line at intervals of every 50, 100 and 1,000 fathoms. When the lead reaches the bottom, a sample of the material forming the sea floor sticks to the tallow, and affords evidence of the fact of the bottom really having been touched. The approximate depths of the ocean, determined by soundings of this character, are shown in Fig. 70.

For greater depths.—The simple plan just described is not suitable for depths of much more than 1,000 fathoms, for the following reasons:

1. The weight is not sufficient to carry the line to the bottom rapidly and vertically.

2. When a heavier weight is used, an ordinary sounding line is unable to draw up its own weight along with that of the lead from great depths, and gives way.

3. No impulse is felt when the lead reaches the bottom; the line continues running out, and if any attempt be made to stop it, it breaks.

4. In some cases lengths of the line seem to be carried along by submarine currents, and in others the line runs out by its own weight, and coils itself up in a tangled mass directly over the lead.

In order to obviate these sources of error, which vitiated some of the earlier observations, the following apparatus (known as the "Hydra Machine") was used by the observers in the famous *Challenger* Expedition, to which we owe so much of our knowledge of the ocean depths: *a* is an iron tube about five and a half feet in length and two and a half inches in diameter. It is

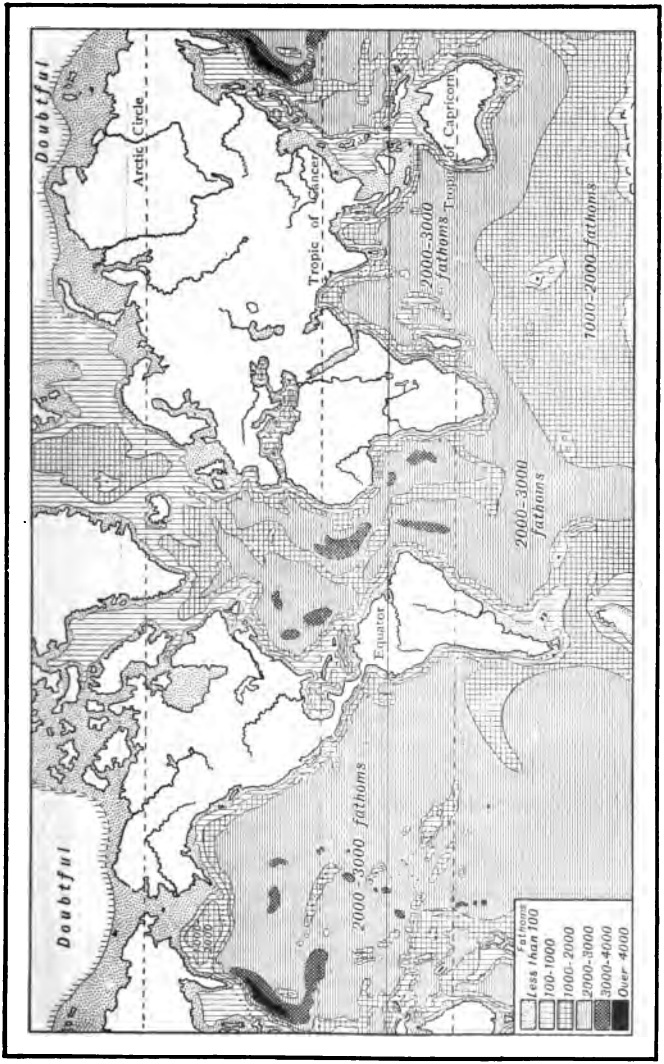


FIG. 70.—Map showing varying depths of the ocean. The 100 fathom line marks the edge of the "Continental shelf."

provided at its lower end, *e*, with a pair of valves which open inwards. Supported by a sling at *c* are several perforated heavy iron weights which are threaded on to the tube. The apparatus is so designed that when it comes in contact with the bottom, the sling is detached, after the tube has penetrated into the material on the floor and filled the lower end of the tube with a specimen, which the valves prevent from escaping. The weights themselves are left behind.

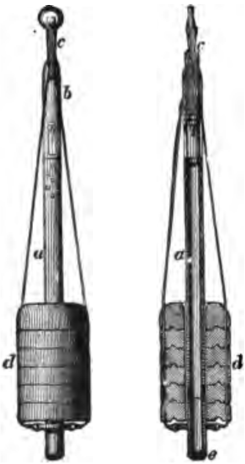


FIG. 71.—The Hydra Sounding Machine.

FIG. 72.—Section of the Atlantic Ocean between Newfoundland and Ireland. Vertical scale about 20 times horizontal scale.

More modern forms of sounding apparatus are more elaborate than the "Hydra Machine," but the principle on which they are constructed is much the same.

Results of soundings.—Atlantic Ocean.—Deep-sea soundings provide data for the construction of sections across the ocean, showing the shape of the basin in which the waters are contained, and enable us to obtain almost as good an idea of its form as if we could drain off the water and walk over the sea floor.

In the case of the North Atlantic, from the west coast of Europe to the east coast of North America (Figs. 72 and 73), there is a gradual slope from the land into the sea; the inclination is nowhere "more than one in twenty-five, or that of a hill of moderate steepness." The depth increases after we get two hundred miles from the Irish coast to about two thousand fathoms, and remains between two and two and a half thousand fathoms for some distance, until the floor begins to rise again into a kind of

submarine table-land of a thousand miles in width, over which the depth of the water is rarely more than fifteen hundred fathoms and generally nearer one thousand fathoms. When the "**telegraph plateau,**" as it has been called, has been passed, the same differences in depth are experienced, though in the reverse order; the water first gets deeper again down the western edge of the submarine table-land and in due course the floor rises again by easy gradations into the Newfoundland bank.

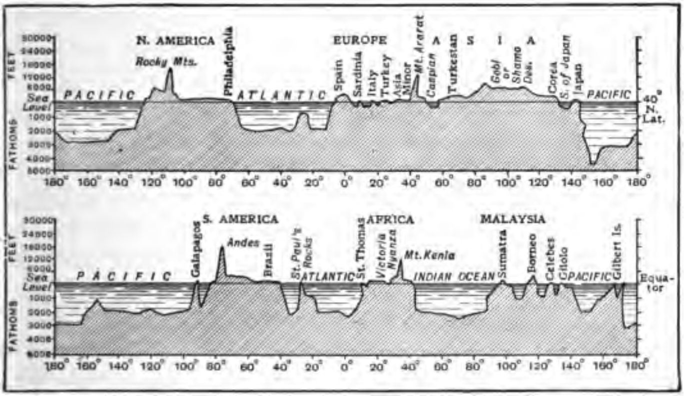


FIG. 73.—Approximate sections round the earth, showing elevation of the land and depth of the sea along the parallel of 40° N. (upper figure) latitude and the equator (lower figure). Vertical scale greatly exaggerated.

The telegraph plateau extends in a northerly and southerly direction throughout the Atlantic Ocean (Figs. 70 and 73), and names have been given to it in different latitudes. Thus, north of the equator it is called the "Dolphin Rise"; while south of the equator it is spoken of as the "Challenger" ridge, the intermediate portion going under the name of the "connecting ridge." The student is recommended to examine carefully the contours of the ocean floors in Fig. 70, and to picture what their appearance would be if the water could be removed and a bird's-eye view of the floors obtained. The absence of such irregularities as mark the surface of the land is very striking. The ocean effectually prevents the atmospheric agencies, which are so active in sculpturing the land into its endless variety of hill and dale, from causing any

similar wasting away of the sea floor. The sea floor is monotonously level. The only abrupt elevations from its even surface occur in the case of oceanic islands, which rise precipitously, and, in the absence of the waters above, would constitute mountains. This is clearly brought out in Fig. 73, where the submarine mountain, the uncovered peak of which forms the island of Galapagos, is seen towering up through more than 3,000 fathoms of water and attaining a total height of 20,000 feet, rivalling that of Mount Chimborazo.

There is thus in the Atlantic a more or less median table-land with a deep valley on either side. In some one or two parts of these valleys decided hollows occur. The first of these "abysses," lying near the Virgin Islands, has a depth of 4,560 fathoms. Another lies to the south-east of North America, between the West Indian Islands on the south and the Bermudas on the north. The soundings here reveal a depth of 3,875 fathoms or upwards of four miles. The third occurs in about the same latitude on the other side of the ocean, to the west of the Canary Islands, and its depth is about 3,150 fathoms. A fourth depression has been found in the South Atlantic, roughly near the middle of the ocean between the east coast of Brazil and the island of St. Helena. The average of all the soundings which have been made in the Atlantic works out to about 2,000 fathoms.

Pacific Ocean.—The Pacific is a deeper ocean than the Atlantic, its average depth being about 3,500 fathoms, though in some places much greater depths have been reached. Thus, off the Ladrone Isles (latitude about 15° N., longitude about 152° E.) a measured depth of 4,575 fathoms, or about five miles, has been recorded; off the Kurile Islands, between Japan and Kamtchatka the depth has been found to be 4,655 fathoms. H.M.S. *Penguin* in 1895 found near the Kermadoc Islands a depth of 5,155 fathoms.

Over several submarine table-lands the water does not exceed a depth of 2,000 fathoms. One of these stretches in a north-westerly direction from the coast of Chile towards the depression near the Ladrone Islands; another of lesser extent occurs to the south-east of the Australian continent, and it is upon it that New Zealand is situated. The islands of the Malay Archipelago

rise from a third, which occupies the area between the south-eastern portion of Asia and Australia. The Pacific Ocean, in fact, presents many remarkable irregularities, a good idea of which will be obtained by looking at an ordinary map and bearing in mind what has been said about islands which occur dotted over the great expanse of water constituting the ocean.

There is no feature of exceptional interest about the **Indian Ocean.** Its average depth can be taken as about 2,600 fathoms. So little precise knowledge of the other oceans is available that no special reference to them is necessary.

Marine deposits.—Samples of the materials covering the sea floor, obtained during soundings, show that the nature of the deposits varies with the depths at which they occur. To quote Dr. J. J. H. Teall, *Natural Science*, March, 1892: "Proceeding outwards from the shore, we first meet with the variable deposits of the littoral and shallow-water zones. Banks of sand heaped up under the influence of tidal currents follow, and wide stretches of mud in the deeper and quieter regions. Here and there occur local accumulations of shells and shelly *débris*. Near the 100-fathom line blue muds are found, and as these are followed down the continental slope, they merge, near its base, into Globigerina ooze—a deposit which extends with wearisome monotony over immense areas. As we descend into the abysses of the ocean, to depths exceeding 2,500 fathoms, the globigerina ooze passes into 'grey' ooze, and this again into red clay—the most widely distributed of all the deep sea deposits." This is illustrated (Figs. 70 and 74) in a striking manner in the case of the Atlantic, where the areas covered by red clay correspond closely with the positions of the abysses. Again, the terrigenous or land-derived deposits are seen to occur chiefly between the shore and the 100 fathom line.

The fact that the deposits in the deepest parts of the ocean contain no materials derived from land supports the belief that while many parts of the earth have been alternately buried beneath the sea and elevated to form dry land, others have remained permanently submerged or have been permanently dry land.

Depths of the British seas.—To British students the study of the contours of the ocean floors becomes most interesting when

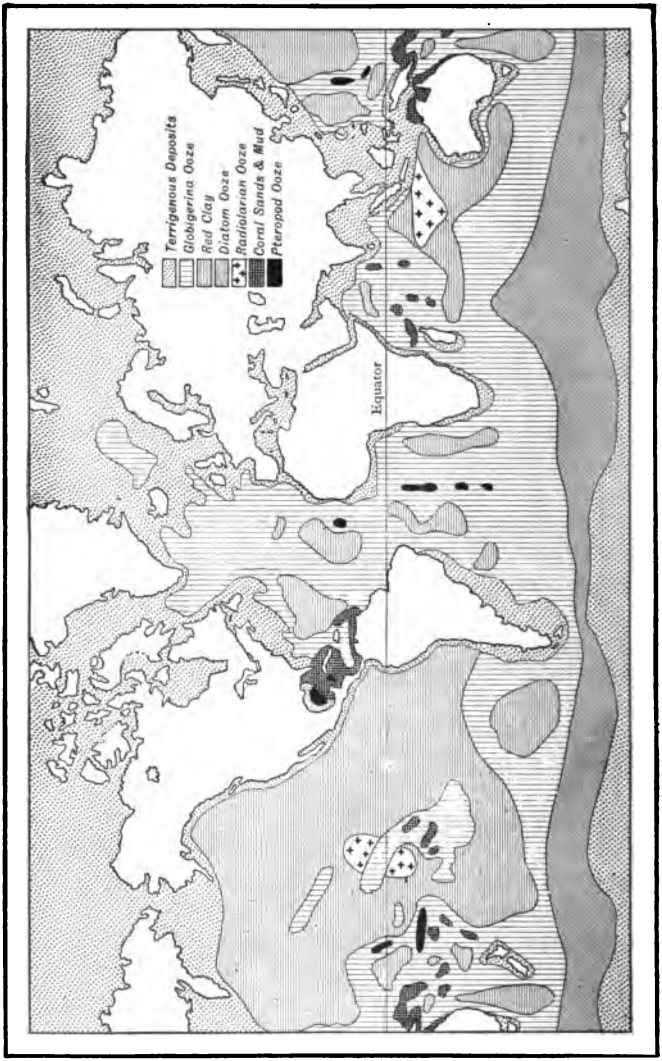


FIG. 74.—Distribution of submarine deposits.

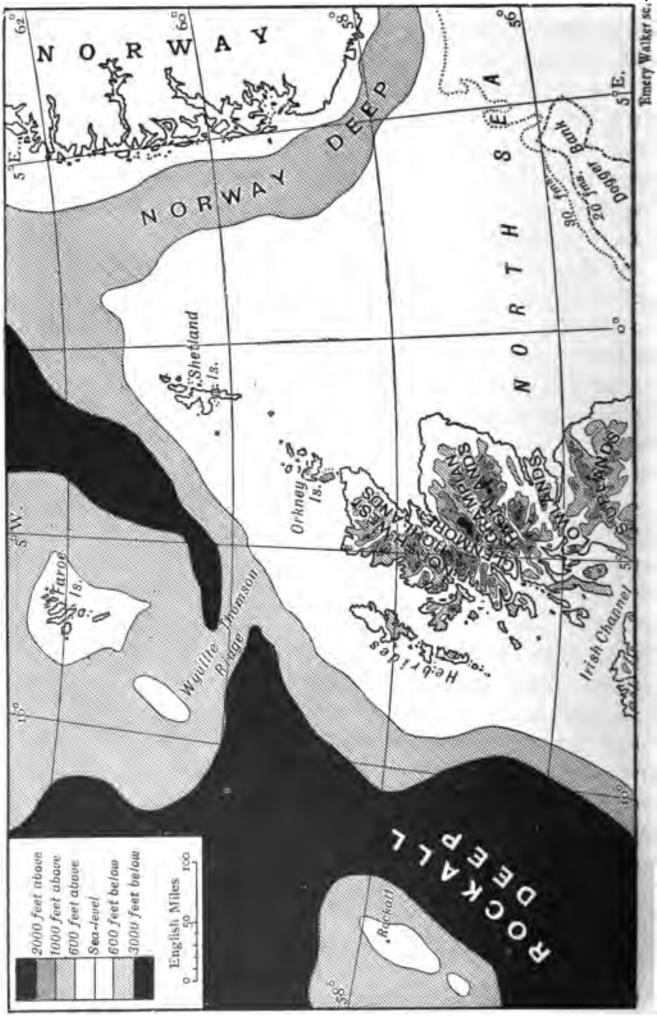
applied to the seas of north-west Europe (Fig. 75). Our islands are essentially a part of the European continent, which really extends along the shallow sea bottom to a line skirting the west of Ireland and Scotland. Beyond this line there is a sudden drop to the depths of the Atlantic. Thus the British Isles are often said to stand on the edge of a continental shelf. For convenience, it is usual to define the edge of the **continental shelf**—the submarine ledge which forms the true margin of a continent—by the contour line of 600 feet below sea level. It is in the shallow seas of the continental shelves that the richest fishing grounds are found.

Sir A. Geikie says*: "If the west of Europe were elevated 200 feet—that is, the height of the London Monument—the Straits of Dover, half of the North Sea, and a large part of the English Channel would be turned into dry land. If the elevation extended to 600 feet—that is, merely the united heights of St. Paul's and the Monument—the whole of the North Sea, the Baltic, and the English Channel would become land. There would likewise be added to the European area a belt of territory from 100 to 150 miles broad, stretching to the west of Ireland and Scotland.

"With an uprise of 600 feet a vast plain would unite Britain to Denmark, Holland and Belgium, and would present two platforms, of which the more southerly would stretch from what are now the Straits of Dover northward to the northern edge of the Dogger Bank, where a steep declivity, doubtless a prolongation of the Jurassic and Cretaceous escarpments of Yorkshire [see p. 232], descends to the northern or lower platform. This submarine escarpment is trenched towards the west by a magnificent valley through which the united waters of the Rhine and Thames would flow, between the Dogger Bank and the Yorkshire cliffs. Another gap further east would allow the combined Elbe and Weser to escape into the northern plain.† Possibly all these rivers would unite on that plain, but, in any case, they would fall into a noble fjord which would then be revealed following the trend of the southern coast line of Norway. Altogether an area more than

* *Landscape in History*, p. 130 (Macmillan).

† "The drainage-lines of the united Rhine, Thames, etc., on the one side, and the Elbe, Weser, etc., on the other can still be partially traced on the sea-floor."—*Ibid.* p. 154.


NORWAY
NORWAY DEEP
NORTH SEA
Shetland Is.
Orkney Is.
Faroe Is.
Wyville Thomson Ridge
Hebrides
Irish Channel
ROCKALL DEEP
Rockall
Dogger Bank
20 fms.
90 fms.
GRAMPIAN HIGHLANDS
2000 feet above
1000 feet above
600 feet above
Sea-level
600 feet below
3000 feet below
English Miles
0 50 100
Emery Walker sc.

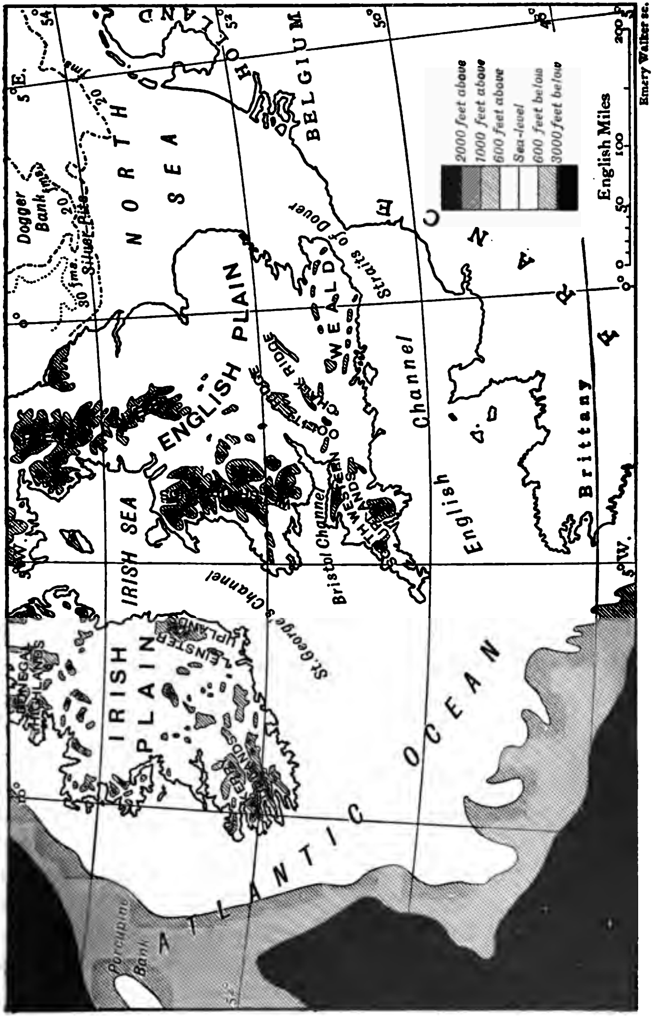


FIG. 75.—Bathy-orographical Map of the British Isles.

thrice that of Britain would be added to Europe. By a total rise of 1800 feet, Britain would be united to the Faroe Islands and Iceland; while the Arctic and Atlantic Oceans would be separated." This description undoubtedly represents a state of things which, comparatively recently, was actual fact, and may be realised again in the future.

The British coast line.—It needs but a slight exercise of the imagination to picture the result which the subsequent subsidence of Britain must have had upon a mountainous area already cut up by deep river valleys. The sea would wind up the valleys, converting their mouths into **estuaries**,* and upland lakes near the coast into sea-lochs or **fjords**, distinguished by remaining shallower at their mouths than inland; the result would be a highly indented coast line. There can be no doubt that the characters of our western seaboard—as contrasted with the more uniform outline of the east coast—are chiefly due to its greater subsidence, after the harder western rocks had been sculptured already into mountains and valleys by the more rapid rivers. The rugged character of the coast line—already marked when the present level was reached—has been subsequently accentuated by marine denudation in the manner to be described in Chapter X.

Similar "drowned river valleys" occur in many parts of the world, and are easily recognised on maps. They seem to indicate subsidence within recent geological times, and the regular contour of coasts recently elevated is equally characteristic. Both types are well shown, for example, on the west coast of North America, the signs of subsidence being obvious north of lat. 48°, and those of elevation southward. Nearer home, other excellent illustrations of drowned river valleys are the fjords of Norway and the straits of Greece; while the islands of the Aegean Archipelago are as certainly the summits of mountains which formerly were part of the mainland.

Comparison of the height of continents with depth of oceans.—In measuring the height of any place it is customary to speak of its height above the **sea level**, using the level of the ocean as a datum line. Every one knows, however, that the rise and fall of the tides causes an alteration of its level near the land twice each

* An estuary is the wide lower part of a river where it becomes tidal.

day. The Ordnance Survey authorities have arranged that, so far as their maps are concerned, "**sea level" shall be the mean height of the sea between high- and low-water mark at Liverpool.** But this is not the only starting-point which is used; the Trinity House authorities measure heights from the high-water mark at London Bridge.

The mean average height of the continents has been estimated at 2,300 feet above the sea level; that is, if the mountains were all levelled and the valleys filled up, this would be the height of the land thus formed.

The mean average depth of the oceans can be put at about 11,500 feet below the sea level. The height of the highest

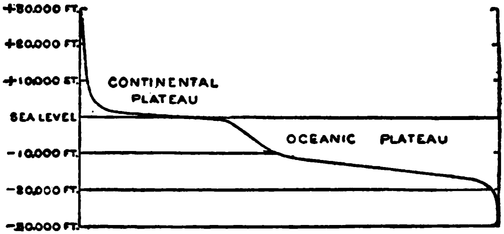


FIG. 76.—Generalised profile showing relative areas of the earth's surface at different heights and depths. (Gilbert.)

mountain is about five miles, and the greatest depth of the ocean is nearly six miles. This at first appears a very great height and depth respectively. But the radius of the earth is 4,000 miles, and if the distance from the top of the highest mountain to the bottom of the deepest abyss in the ocean is taken, a length of eleven miles only is obtained, or rather more than one four-hundredth of the total radius.

By instituting a comparison of the average height of the continents with their total area, which can be taken as roughly 51,886,000 square miles, or of the average depth with the total area of the oceans, which is approximately 145 millions of square miles, the student will be impressed with the insignificance of the land elevation and with the comparative shallowness of the oceans.

Variations in sea level.—For convenience in making vertical measurements, it is assumed that the surface of the sea—adopted

as zero level—is everywhere the same distance from the centre of the earth, and that any change in the height of a given place above, or in its depth below, the sea level is due to movements of the land. Both these assumptions are only approximately true. Apart from the slight flattenings of the surface in polar and other regions (p. 68), the sea level is certainly modified locally by various circumstances. It must be higher round the coast than in the middle of the ocean, just as the surface of water in a tumbler is higher where it touches the glass than it is in the middle. The level must be permanently raised in some regions and depressed in others by the continuous action of prevailing winds and ocean currents. Lastly, there is some evidence that certain "raised beaches" owe their present height above sea level not to elevation of the land, but to subsidence of the sea caused by a sinking of the ocean floor.

EXERCISES ON CHAPTER VI.

1. Explain carefully the meaning of the terms *mountain*, *hill*, *plain*, *plateau* and *pass*. Mention any examples which occur to you of (*a*) a *range* of mountains, (*b*) a *group* of mountains, (*c*) a range of hills on a plateau and (*d*) a great mountain pass. (O.P.)

2. Give three examples of salt lakes, and explain why they are salt. (C.S.)

3. The coast line of many countries is in some parts much indented and in others unbroken. How does the country inland from the one kind of coast usually differ from that inland from the other? Give examples. (O.P.)

4. What instances do you know of dry land at a lower level than that of the sea? How do you account for them? (C.J.)

5. Describe the form of the deep-sea bottom as compared with that of dry land. (C.J.)

6. Describe the form of the floor of the North Atlantic. How do the deposits formed in the centre of the ocean differ from those formed on its margin? (C.S.)

7. What conditions lead to the formation of salt lakes, and what deposits would you expect to find in them?

8. What parts of Europe *or* Australia *or* North America are not drained by rivers flowing to the sea? State the nature of the climate of these regions in the continent selected, and name and describe very briefly the chief river of their inland drainage area. (L.J.S.)

9. What do you mean by a *natural* region? Taking any continent you like, subdivide it into natural regions. (Prel. Cert.)

10. Compare the coast lines of North-west Europe, West Africa and the Atlantic side of South America. Explain why they differ so widely in their conformation. (Prel. Cert.)

11. What exactly do we mean by the term "salt lake"? In what regions of the world are salt lakes found? How are they formed? Name examples of lakes which are very salt, and of others which are only slightly brackish. (P.T.)

12. To what circumstances do you attribute the existence of the following?—

(*a*) The long narrow fjords on the west coast of Scotland.
(*b*) The smooth outline on the Norfolk coast.
(*c*) The granite hills of Dartmoor and Cornwall. (Cert.)

13. If the land rose 600 feet, what changes would take place in the geography of north-western Europe?

14. Describe briefly the disposition of land and water in the Southern Hemisphere, and give some idea of the difference in the relative amount of land and water to be traversed by men going round the world (*a*) at the Equator, (*b*) at the Tropic of Capricorn, (*c*) at Latitude 60° S. (N.F.U.)

CHAPTER VII.

RIVERS AND GLACIERS.

17. WATER AS A TRANSPORTING AGENT.

1. Dissolved and suspended matter in water.—(*a*) During a heavy shower collect a glassful of rain water, and also one of the water flowing along a gully or gutter. Allow the second sample to stand, and notice the manner in which suspended particles of sand and mud settle to the bottom. How do the upper layers of the deposit differ from the lower layers? Does the water rapidly become quite clear? If not, filter it through filter, or blotting, paper in a funnel in the manner shown in Fig. 77. Similarly, filter a little of

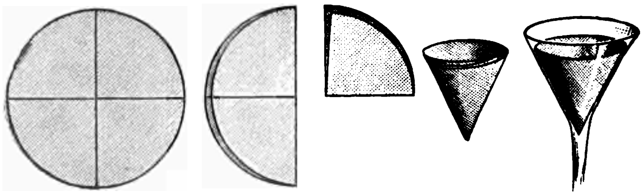


FIG. 77.—Method of filtering through filter-paper in a funnel.

the rain water if necessary, until both liquids are quite clear. Label the vessels containing them. Can you see any difference between the two filtered liquids?

(*b*) Pour any convenient measured volume of the clear rain water into a porcelain dish, or saucer. Into a second dish, or saucer, pour an equal volume of the filtered gutter water. Put the dishes over boiling water so that the steam will play on the outsides of the dishes and cause the contained water to evaporate without spurting (Fig. 78). When all the water in the dishes has disappeared, examine the residues,

if any, left in them. Do the residues differ in appearance, or amount, in the two cases? How do you account for the differences? If a delicate balance is available, weigh each dish with its residue, then clean and dry the dishes and weigh each of them again, and obtain, by difference, the weights of the residues.

FIG. 78.—Simple water bath.

2. Loss of weight of bodies suspended in water.—(*a*) Suspend any convenient object, say the glass stopper of a bottle, with thread, from the hook to be found over the pan of a laboratory balance. Weigh the object, and then, using a wooden bridge, arrange a glass of water so that the object is immersed in the water. Do the weights in the other pan still balance it? If not, find the difference in weight which is caused by immersion of the body in water. What proportion of the weight is "taken off" by the water?

(*b*) Compare the effort required to lift a heavy weight (i) in air, (ii) under water.

3. Carrying power of running water.—When water is flowing freely along a gulley or gutter, collect samples from various points at which the flow differs in rapidity. Find out, by examining the deposit, whether the solid particles carried by the water differ (i) in size, (ii) in amount, according to the speed of the current.

4. Line of maximum velocity of a stream.—(*a*) Into a wide test tube pour glycerin to the depth of an inch, and stir it vigorously with a rod until it contains an abundance of small air bubbles. Then slope the tube so that the glycerin flows in a slow stream. Compare the rates of flow—as made clear by the suspended bubbles—at the surface, the sides and the bottom of the stream of glycerin. Repeat the experiment several times and notice whether the motion of the air bubbles is always parallel to the general direction of flow.

(*b*) (*Outdoor work.*)—When rowing up-stream on a river, compare your rate of progress in mid stream with that near the bank.

5. Measurement of velocity. (*Outdoor work.*)—Provide yourself with a number of corked bottles, each suitably weighted (by gravel or lead shot in it) and carrying a flag at the top. Measure a convenient length along the bank of a stream, and time the journey, along this length, of bottles started at different points across the stream. Take the mean of the velocities of the various bottles as the velocity of the river over this stretch.

The action of running water.—Rain water which has fallen through unpolluted country air reaches the ground in a condition of almost entire purity. In its fall it has taken up more or less of the gases of the atmosphere, but it is as yet free from solid matter. But the moment it comes in contact with the earth it begins to exercise its **power of solution** on the solid particles of rock and soil. Certain constituents of these become dissolved and lost to view in the water as completely as a teaspoonful of table salt dissolves and is lost to view when stirred in a tumbler of water. In this state of solution such materials are carried to a stream and ultimately reach the sea. The solubility of the materials of rocks and soils is not dependent upon their hardness or softness, on their brittleness or on any other physical character, but is decided by their chemical composition only.

But the water carries with it not merely dissolved matter, but also (1) **suspended particles** which settle whenever the water comes to rest, and (2) masses of varying sizes and shapes which are pushed or rolled along the bed of the stream.

The extent to which solid bodies are transported in this manner depends upon many circumstances. Of these, one of the most significant is the lifting force which water—even when at rest—exerts upon all solid bodies immersed in it. The force is in each case equal to the weight of the water which the solid displaces. With an immersed body measuring one cubic inch, for example, the force is equal to the weight of one cubic inch of water. This upward force, acting alone, can, of course, actually raise from the bottom only those particles which are bulk for bulk lighter than water, whereas most rock fragments are heavier than water.

But in flowing water additional forces are brought into action. There is, first of all, the onward current of the stream, the power of which to transport the bodies in its bed varies *as the sixth power of its velocity*. "If a stream flowing with a given velocity is able to move stones weighing one pound, by doubling the velocity boulders weighing sixty-four pounds can be carried; and if the velocity were increased ten times, rocks weighing one million pounds could be moved." *

Secondly, the friction of the water against the sides and the bed of the stream causes *eddies* which result in various **upward currents**. These secondary currents vary in force according to

* Russell's *River Development* (Murray).

many circumstances, but they are nearly always stronger in swiftly flowing than in slower streams, and their actual power of raising particles of sand, gravel and the like from the bottom depends largely upon the speed of the main current.

"In any channel, . . . the velocity of forward flow is greatest near the centre and least near the sides and bottom, and if it were possible to obtain a state of affairs in which the motion might take place in stream lines parallel to the axis of the stream, we should have, with steady flow along a straight reach of the channel the *velocity greatest on the surface and at the centre* of the stream, and the water surface level from side to side. In practice this is modified by the eddy formation which always takes place at the sides of a stream." The result is that, "except in a broad, rapid and shallow stream, the **line of maximum velocity** is at some depth below the surface. . . . On a calm day it usually ranges from about one-tenth to four-tenths the depth of the stream." *

Now, the **rate of flow** of a stream of water—which affects its transporting power so greatly—is in its turn dependent, other things being equal, upon the slope of its bed. It follows that in most cases a stream contains the greatest amount of suspended matter where its bed is steepest; while it deposits an increasingly greater amount of sediment as its bed becomes flatter and its flow less rapid.

Again, the rapidity even of a stream flowing over a bed of uniform inclination must obviously vary with variations in its width; for we may assume that, under ordinary conditions, the same quantity of water is passing all points in the same interval of time; and when this is so the speed through a narrow gorge must be greater than along a wider channel.

Where, either from the widening of its channel or from the more level character of the ground over which it is flowing, the speed of a stream becomes checked, the solid matter in suspension is deposited—the coarser and heavier materials first and the finer particles later. A river passing through a lake may be, from the former of these causes, almost entirely freed from suspended matter; the beautiful clearness of the water of the River Rhone

* *Vide* A. H. Gibson's article "On the Depression of the Filament of Maximum Velocity in a Stream flowing through an Open Channel" (*Nature*, April 1, 1909).

at Geneva, so often cited, is an excellent example, but others as good may be found in our own country.

18. THE WORK OF A RIVER.

1. Experiment to illustrate the origin of a river. (*Outdoor work.*)—Build up a mound of wet earth or clay, say a yard in diameter and a foot in height, and shower water upon it from a large watering-can. Observe (*a*) the various directions in which water runs from the highest parts (watershed) of the mound; (*b*) the union of small streams to form larger ones; (*c*) the occasional deflection of a stream by an obstacle in its path; (*d*) the gradual formation of valleys by streams and their tributaries.

2. The formation of springs. (*Outdoor work.*)—Build up a mound with two or three alternating layers of sand and clay, and shower water upon it from a watering-can. Note carefully how the points of origin of springs are related to the character of the material above and below them. How do sand and clay differ in the ease with which water percolates through them?

3. The formation of a delta. (*Outdoor work.*)—Either immediately after a shower on any "waste ground" conveniently near, or by means of an artificial mound and a watering-can, as in Expts. 1 and 2 above, study the deposition of suspended matter by a stream on reaching flat ground. Look for examples of such a stream being blocked by sediment it has itself deposited, and study the manner in which it may have formed fresh channels through such sediment.

4. Field study of rivers. (*Outdoor work.*)—(*a*) Examine the Ordnance map of your district to find approximately where a convenient river has its source. Make an excursion to the source and make the following observations. Is the source at the top of a hill or at some distance down the slope? Does it consist of a spring? Can you suggest why a spring should be found in this position? How is the spring supplied with water? Follow the stream in the direction of its flow. Of what kind of rock is the bank of the stream? Is the channel of uniform width? If not, can you find any relation between its width and the hardness of the material forming the banks? What observations would lead you to suppose that the river has excavated its own channel? Collect a glass of water at intervals and observe whether it contains much suspended matter. Would a river of clear water or one carrying much suspended matter be more likely to deepen its channel? Would you expect a river, in general, to become deeper in a steep valley or on a fairly flat plain? For what length does the river seem

to be engaged actively in excavating its valley? Find out from the Ordnance map what is its average slope (expressed in feet per mile) during this length. Does it wind about much in this part of its course?

(*b*) Where does the river begin to take on a winding course? Follow it round a bend and observe, by floating bits of paper or wood, or by the method of Expt. **17**, 5, whether it flows more rapidly under the concave or the convex bank. Which, if either, of these banks shows signs of being undercut by the water? Which, if either, bank seems to be formed to any extent of material deposited by the river? Will the river, by long continuance of such action, tend to alter its course? Do you see any sign that a "short cut" may eventually be formed between one reach and another? Look, on the Ordnance map, for other such loops or "meanders" in rivers, and in each case estimate approximately the slope of the land over which a river follows a winding course. Study the course of the River Dee on Fig. 22, and compare the slopes of the concave and convex banks.

(*c*) If you have access to the place where a river discharges into a lake, or into the sea, look for signs that it has been compelled to form new channels through ground formed from its own deposits.

5. The profile of a river.—(*a*) Draw the profile of the River Thames by the method used for road-book sections (Fig. 25) from the following particulars.* Height at source, 600 ft.; 9 miles from source, 300 ft.; 20 miles from source (near Lechlade), 200 ft.; 92 miles from source (near Great Marlow), 100 ft.; 140 miles from source (London Bridge), 25 ft. Use a vertical scale of $\frac{1}{2}$ in. to 100 ft., and a horizontal scale of $\frac{1}{2}$ in. to 10 miles.

(*b*) To suitable horizontal and vertical scales, draw the profile of the river studied practically in Expt. 4 above.

An instructive miniature.—No opportunity of studying at least the upper part of a river valley by personal observation should be lost. "It is," says Lord Avebury,† "a beautiful and instructive miniature. The water forms a sort of small-meshed net of tiny runnels. We surprise the river at its very commencement: we can find streamlets and valleys in every stage; a quartz pebble may divert a tiny stream, as a mountain does a great river; we find springs and torrents, river-terraces and waterfalls, lakes and deltas, in the space of a few square yards, and changes pass under our eyes which on a larger scale require thousands of years.

* De Rance (*Proc. Geol. Assoc.*, vol. iv. 1875).

† *The Scenery of England*, p. 322 (Macmillan).

"And as we watch some tiny rivulet, swelling gradually into a little brook, joined by others from time to time, growing to a larger and larger torrent, then to a stream, and finally to a great river, it is impossible to resist the conclusion gradually forced upon us, that, incredible as it must at first sight appear, even the greatest river valleys and plains, and the general configuration of the land, though their origin may be due to the initial form of the surface, are due mainly to the action of rain and rivers."

The origin of a river.—The rain* which falls on high lands at once begins to flow downhill. If the surface of the ground is **impervious**, the water runs along it, taking advantage of every slope to find a lower level. If the surface soil, on the contrary, is composed of sandy, gravelly or other **pervious** material, the water sinks through the ground until it comes to an impervious layer, which

FIG. 79.—Surface springs; *a*, are impervious; *b*, porous beds.

arrests its vertical progress, and it then flows along this layer until it reaches the surface as a **spring**.

Surface springs.—The formation of simple springs of this kind will be understood readily by reference to Fig. 79. This illustration shows a section across a valley. The beds (*b*) are made up of sand and gravel, those marked (*a*) are of clay. The rain which falls in this neighbourhood will flow partly over the surface, but the greater part will sink into the ground and will meet with little obstruction to its course until the bed of clay is reached, since sand and gravel are porous. Reaching the bed of clay, it will be unable to sink further, and consequently will collect at the line of junction. The result will be that where the sand has been worn through, exposing the clay (*a*) as shown in Fig. 79 between *ss*, the water, which has collected in the manner described, issues in the form of a spring. Because of the nearness of the underground water to the surface, springs of this kind will be immediately

* The origin of rain is described in Chapter XIII.

dependent upon the rainfall. In seasons of drought the spring will cease, while in rainy years there will be an abundant supply of water. The water which issues from surface springs is very liable to be contaminated with drainage and other impurities from the surface.

Artesian wells are artificial springs, and as such have, of course, no share in the formation of rivers. They may, however, be conveniently referred to here. They are only possible where the rocks are arranged in a manner more or less as shown in Fig. 80, which is drawn to give a rough idea of the way the rocks lie round and under London. The basin-like character of the rocks is very much

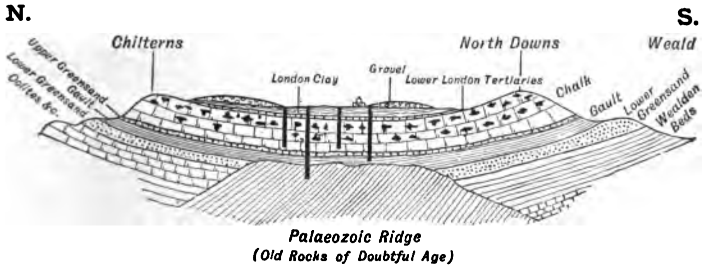


FIG. 80.—Section from the Chiltern Hills to the North Downs, to show the London Basin and the principle of an Artesian Well. The basin-like form is much exaggerated. (Drawn by Mr. W. C. Simmons.)

exaggerated so as to exhibit the arrangement on which the possibility of such a well depends. Near the surface are beds of clay, known as the *London Clay*; then follow beds known as the *Lower London Tertiaries*; they are made up largely of porous sands, but thin layers of clay occur at different levels. These clayey strata being impervious, serve to retain the water which sinks down into the sands, and water gets stored up at the junction. If a boring is made through the London Clay down into these sands and gravels, the water which has collected there seeks its own level, and being much higher near the outcrops of the lower beds, the water flows out at the boring and rises to this height, or as high as the water has collected in the sands. In Fig. 80 borings are shown penetrating the lower beds; some of these beds are of chalk, which is remarkable amongst other things for the large number of crevices which it contains, and in these the water collects in a manner which cannot, however, be predicted, since the cracks follow no definite order; the clayey *Gault* below the

chalk prevents the water from escaping below, but if one of the numerous fissures be struck by the boring, the supply of water from the outlet at the surface is much augmented.

Wells of this kind are called *Artesian* wells, from the name of the French province Artois, where they were first constructed. Fig. 81 shows the water issuing from an Artesian well in Australia.

FIG. 81.—Artesian Well in Australia.

Rivers.—Part only of the rainfall of a district sinks into the ground and gives rise to springs, another larger portion flows over the surface, collecting into runnels, which continually unite, until at last a stream is formed. Is is by the union of streams of this kind, together with those which have their origin in springs, that

rivers are formed. Rivers can thus be regarded as the surplus rainfall running off to rejoin the ocean.

In addition to the water, however, as has been seen, rivers contain a large amount of mineral substances dissolved, which being added continually to the ocean, maintain the saltness of sea water. Not only are dissolved materials thus removed from the land by rivers, but also a large amount of suspended matter, which is hurried forward by the force of the moving water; concerning this, more will be said later.

Terms used in describing rivers.—It will be well first to explain the terms which are in common use in describing a river. The commencement of the river is called its **source**; this may, as in the case of the Rhone, be at the foot of a glacier below the snow-line, where the temperature is high enough to cause a constant melting of the snow or ice; or it may arise from a spring, marsh, or lake, in all of which cases it is often difficult to locate the exact spot where the river begins. Indeed, speaking generally, it may be said that less is known of the source than of any other part of rivers.

The river empties itself into the ocean at its **mouth**, and proceeds from its source to its mouth along the direction of its **course**. Standing at any spot along the course of a river and looking in the direction of the mouth, that is, along the direction in which the water is flowing, we call the bank on the right the **right bank**, the other the **left bank**.

The water of a river represents the drainage of a certain tract of country, and a name is given to this area; it is known as the **river basin**. The highlands dividing one river basin from another constitute a **watershed** (Fig. 150).

The upper course of a river.—The course of a river is often divided into three portions, viz. the *upper*, *middle* and *lower* courses. The upper is that part which flows down the steep mountain slopes, and is often called the mountain-track; it is characterised by its **waterfalls**, where the water drops a considerable height from one ledge to the next; by its **rapids**, where the river's waters are held between narrow confines, and by its **cascades**, which are simply successions of waterfalls.

It is in its upper course that a river accomplishes the greater part of its work of erosion or wearing away the rocks over which it

passes. The action is chiefly due to the friction of the coarser fragments which the river moves along its bed, and the erosion is

FIG. 82.—Ashdale Falls, west of Whiting Bay, S.E. coast of Arran. (Photographed by the Geological Survey of Scotland.)

naturally greatest where the bed is steepest and the flow most rapid. The result is that the deepening of the bed near the source continually **cuts back the source** itself. The consequences of this

action are ultimately very far-reaching. The gradual cutting back of the source of the river obviously increases the distance from source to mouth, and therefore lessens the average slope of the river bed. It is plain, also, that some amount of shifting of the watershed is involved where a river on one side of the divide is cutting back at a greater rate than a stream opposite to it on the other side. In this process, the more active of two such streams often cuts into the head waters of the weaker river, and—

Photo. L. V. Horn.

Fig. 83.—Small potholes in the bed of the River Wharfe at Bolton Woods, Yorkshire.

if it provides these head waters with a greater fall—annexes them. This is known as **river capture**; some apparent instances of it in our own country are mentioned on p. 235.

The result of friction on the excavating tools themselves is no less marked. As the stones and gravel move along, the persistent rubbing against the channel and one another which they undergo causes them to get gradually smaller and smoother, eventually giving rise to the "water-worn" appearance which characterises the pebbles at the bottom of a stream or river. The suspended material causes too great a degree of turbidity in the water for the more slowly moving layer on the bed of the river to be visible.

Where eddies are produced in the course of a river the loose fragments are whirled round and round and tend to produce hollows, called **pot-holes**, in the river's bed (Fig. 83).

The most important factor determining the extent to which this wearing away goes on is, however, the nature of the rocks over which the river flows. Hard rocks will be excavated to a much smaller extent than soft ones. One of the best examples of this is afforded by the falls of Niagara, situated between Lake Erie

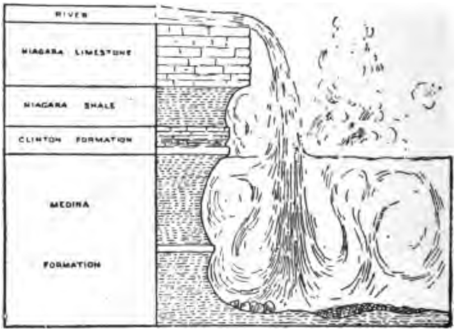


Fig. 84.—Section of the rock at Horseshoe Falls, Niagara. Scale: 1 inch = 307 feet.

and Lake Ontario. The river flows from the former lake to the latter, and passes over a series of beds arranged as shown in Fig. 84, which shows a section of the rocks at the Horseshoe Falls. The bed of the river is formed by the hard Niagara limestone which overlies the softer shales and sandstone. The water as it rushes over the fall dashes against the underlying softer rocks and wears them away at a great rate, thus undermining the limestone, which eventually, by its own weight, falls into the rapids below and is washed away.

That this kind of action has being going on for some time, and at a rapid rate, is shown clearly from the following considerations. At Queenstown, seven miles distant from the Horseshoe Falls, the limestone forms an inland cliff or **escarpment**, and a deep trench extends from this place back to the falls. An examination of the nature of the gorge makes it evident that the river has eroded a channel seven miles in length. Careful observations

give as the yearly amount of erosion at these particular falls 2 feet 2 inches. From 1848 to 1890, some 275,400 square feet of rock had been washed away (Fig. 85).

A magnificent instance of river erosion is afforded by the **cañons** of Colorado, which is almost rainless. These cañons are gorges with, in many cases, nearly vertical sides cut out of horizontal beds of soft rock by the river found at the bottom of the ravine. This condition is, however, most characteristic of small (*i.e.* young) cañons; the sides of the large cañons—which are in a more advanced stage of development—are generally much less steep, since each consists of a series of steps. In the Colorado Cañon (Fig. 86), for example, which is the largest known, the generalised slope of the sides is less than 15°.

A striking example of the erosive action of the upper course of a river is seen near Meiringen, in Switzerland, where the Aar, a tributary of the Rhine, has cut its way through the mountains for

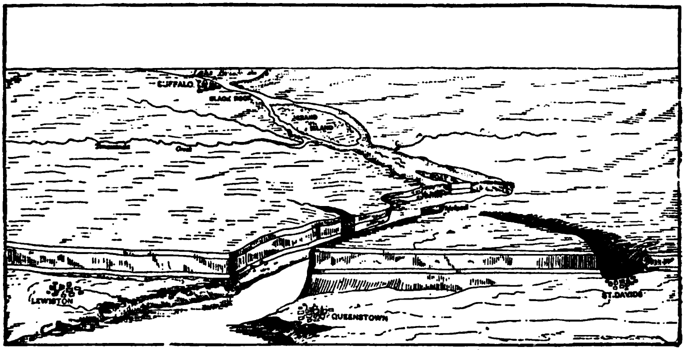


FIG. 85.—Bird's eye view of the Niagara River. (Gilbert.)

nearly a mile, forming a deep gorge, the sides of which, in parts, are almost vertical.

It ought to be remembered that even in the upper course of a river the valley is not only being *deepened* in this manner, but is also being *widened* by rain, wind, and other agents which break up the valley sides and favour the incessant fall of loose earth and stones to the bottom. The normal result is that the valley becomes V-shaped in cross-section (Figs. 16 and 86). It is therefore in

districts where the erosion of the bed of the stream outruns the widening process, that gorges, cañons, and steep valleys generally are produced. Conditions favourable to their development are obviously scarcity of rainfall, swiftly flowing streams, and rocks

Photo. Underwood & Underwood.

FIG. 86.—The Colorado Cañon, about one mile deep, and from 8 to 10 miles wide at the top.

which, from their hardness, composition, or horizontality, do not readily collapse.

In the case of every river, however, the process of excavation comes ultimately to an end, for plainly a river cannot deepen its valley below the level of its own mouth, nor a tributary excavate its bed lower than that of the main stream, since to do either would be to reverse the direction of flow. Thus each river at last attains what is called its **base level of erosion**, at which all excavation of its bed ceases. In the course of ages the valley sides themselves must also be levelled, and the final result is a **peneplain** (*i.e.* almost a plain).

The middle course of a river.—The middle course of a river differs chiefly from the higher portions in the fact that here its

valley is being widened rather than deepened. The decrease in the steepness of its channel is marked by a corresponding diminution in its velocity, and it is chiefly in this part of its journey to the sea that it is joined by other, often equally important, streams called **tributaries.** The place where two such rivers join one another is called their **confluence.**

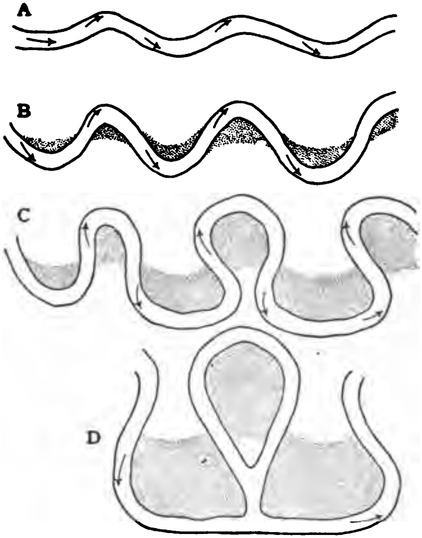
The character of the river's course will depend upon the rate at which the steepness diminishes. If it flows over a country where the altitude decreases very gradually, it will wind about, seeking the place of greatest slope, and will have a long, meandering course. On the other hand, should there be a regular fall towards the sea its path will be straighter, though even then its direction will be influenced by the hardness or otherwise of the rocks over which it flows.

It is in its middle course that a river begins to deposit appreciable amounts of sediment as a result of diminished speed of flow. Such deposits receive the general name of **alluvium.** At the foot of a steep hill—especially in a region subject to very scanty or infrequent rains—a fan-shaped or conical deposit is often formed in this manner; and the union of such *alluvial fans* produced by neighbouring rivers has given rise in various parts of the world to *alluvial plains.* The upper basin of the Indus may be quoted as an example. Such plains are often called *piedmont alluvial plains* to distinguish them from the level expanses produced by the meandering of rivers in the next part of their course (Fig. 88).

Where it encounters obstacles which, over steeper ground, would have been insufficient to change its direction, the river may now be compelled to turn aside, so that its course consists of a succession of pronounced curves or **meanders.** Thus, as a result of its diminished energy, the river in this second stage of its journey tends rather to widen than to deepen its valley as it turns from side to side, and to produce equality of surface in its neighbourhood.

It will be interesting to consider the results which may follow the deviation of a river out of its direct course, caused by some obstruction in its path. When it has turned aside, it tends to continue in its new direction, in accordance with Newton's First Law of Motion (p. 72); on the other hand, the force of gravitation is pulling it back to its former line of flow, and presently, as

a compromise between these forces, added to the resistance offered by the "outside" bank, the river describes a loop, such as is shown in Fig. 87. It is plain that the force of gravity will have less effect over a slight slope than over a steep one, so that rivers have a tendency to produce the greatest curves over the most level country. Many other circumstances must, however, be taken into account in any attempt to explain the phenomena completely.



A. B. C. *Stages in the development of Meanders. Alluvium dotted.*
D. *Oxbow Lake or Mortlake*

Fig. 87.—Development of the middle course of a river.

Further, it may be observed that the current strikes with more directness and force on the outside or concave bank of the curve, and therefore undermines this bank and gradually cuts it back. This action is the more pronounced where the curves are sharp, and an examination of Fig. 87 shows that the natural result is for the two ends of the loop to approach each other, as their concave banks are excavated, until at length (Fig. 87, *D*) they join, and the river once more flows in a fairly direct line. The loop is often left as a pool of standing water, surrounding an island. Such a pool is sometimes called a "mortlake." The American term of "Ox-bow lake" is better known. A mortlake is shown in the course of the River Wyre in Fig. 15.

On the other hand, whilst this is in progress, the convex banks, where the current is slowest, are receiving continual deposits of material (alluvium) which the river has carried in suspension from the hills, so that these banks become gently shelving (Fig. 22) as they extend more and more inward. The net result of all these processes is, as was stated above, to widen and level the river valley, converting it into an **alluvial plain** (Fig. 88).

After heavy rains, a river often overflows in the middle part of

its course. The sudden checking of the speed of the overflowed water causes the deposition of its suspended matter. This gradually builds up embankments above the general level of the plain.

River terraces.—It sometimes happens that a valley bottom is raised by earth movements. The general gradient of the river is thereby increased, and active erosion of the bed recommences even in the middle course, so that the stream eventually flows at a deeper level than before. The former banks of the stream are

FIG. 88.—River meandering in an alluvial flat, Laramie Basin, Wyoming. (From *Bull. U.S. Geol. Surv.*, No. 364, 1909.)

then sometimes to be seen as **river terraces**, forming more or less horizontal shelves along the sides of the valley.

The formation of a delta.—As the river continues its course towards the sea or lake into which it discharges itself, its fall becomes slighter and slighter, and its rate of flow slows down. The materials carried in suspension are deposited, the gravel and sand first, the finer materials later, until only the finest mud remains in suspension. Even this settles gradually to the bottom when at length the flow is checked entirely. The deposit accumulates in a fan-shaped, conical slope (Fig. 89), called, from its shape in the case of the Nile, a Delta (Δ). This is of varying steepness, according to the suddenness with which the current is

checked; and unless it is removed by tidal action it in time blocks the outlet of the river, so that a new channel or channels must be formed. Such new channels naturally tend to form secondary deltas of their own, and eventually a town which was originally on the coast may be separated from the sea by some considerable tract of land formed in this manner. The town of Adria, which was once a port on the Adriatic, is now twenty miles inland owing to the formation of the delta of the river Po.

Photo. Frith & Co.

FIG. 89.—View of Ullswater from Raven Crag, showing a delta. The river (Glenridding Beck) is seen flowing through the delta and entering the lake on the left (west) bank.

In order that a delta of this order may be formed several conditions must hold good.

(1) The coast at the mouth of the river must be sheltered;

(2) There must be an absence of currents and tidal movements in the waters of the sea into which the river empties itself; and

(3) The velocity with which the river flows into the sea must not be sufficiently great to carry the suspended material far away from the coast, *i.e.* the materials must be deposited in the sea near the river mouth more abundantly than they are carried away by the movements they meet with in the sea.

Fig. 90 shows the delta which has been thrown down by the River Nile. The area enclosed by lines joining Cairo, Damietta, and Rosetta is in the shape of a triangle. From an examination of the nature of the deposits forming the country between Cairo and Damietta, it is clear that at one time the Nile entered the sea at the former place, and that the alluvium which extends from it to the Mediterranean, a distance of 100 miles, has been thrown down gradually by the river. The distance from Rosetta to Damietta is 90 miles, but from the extreme mouths of the Nile, as

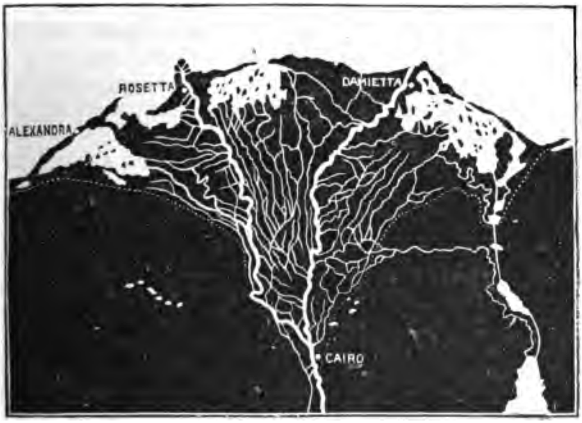


FIG. 90.—The delta of the River Nile.

shown by the dotted line in Fig. 90, the distance is more nearly 200 miles. Borings have been made in the Nile delta, and have revealed the fact that the alluvium reaches to a depth of 120 feet. Some idea of the immense amount of erosion in the upper parts of the river's course which this represents is thus formed, and the necessity for some compensating influence to prevent the whole of the land being worn down to the sea level is appreciated; to this attention will be directed later.

In the case of certain other of the large rivers of the globe, deltas of still greater magnitude have been deposited, and amongst these the Mississippi, the Ganges and the Brahmaputra may be mentioned.

River profile.—A section drawn, as in Expt. **18**, 5, to show the changing gradient along the whole course of a fully developed river, reveals a number of instructive differences between the various portions. In the mountain tract, where the river is excavating its bed, such a river profile is steep, often interrupted by waterfalls, and *concave* to the sky. In the lower part of its course the profile is more gently curved, and is slightly *convex* to the sky, owing to the deposits of alluvium.

The normal cycle of erosion.—When any area, previously submerged, is raised above the surface of the sea, it is at once exposed to the attacks of rain, running water, and other agents of denudation. For a time their action produces increasing irregularity of the surface. At first the rivers are shallow, naturally take the shortest courses to the sea, are, in a general sense, parallel to each other, and have but few tributaries. Later, the direction of flow is more and more determined by the ease or difficulty with which rocks of different degrees of hardness or solubility are eroded. Waterfalls, gorges and escarpments are formed; watersheds become zigzag; and "river capture" gives rise to increasingly complicated tributary systems. As time goes on, more and more material is removed from the higher ground and spread out in alluvial flats or deltas; waterfalls and other irregularities in the beds of the streams are worn away, so that the "river profiles" become smoother and flatter; and finally the "peneplain" condition completes the cycle. These various stages in the modification of the land surface are often described as youthful, mature and old. They are to be studied in the upper, middle and lower course respectively of a typical river.

Such a normal cycle is of course liable to be interrupted by movements of the earth's crust, by changes in the sea-level, or by glacial action (p. 163), so that an area in an advanced stage of erosion sometimes acquires a new lease of "youth," with a corresponding effect upon the topography.

Tidal rivers.—In the case of those rivers which flow into a long narrow opening of the sea, as, for instance, the Thames and Severn, the movements of the sea will influence the height of the river, to distances from its mouth varying in the case of different rivers. One of the most familiar of the movements of the sea is the **tides** (Chap. XI.). The tides are great waves which travel round the earth as it rotates, and are caused by the differential attraction of the sun and moon upon the earth. These waves are noticeable at all places on the coast, causing the

phenomena known as high and low water. In the case of the Thames (Fig. 91) the influence of the tides is felt as far up the river as Richmond, where the first lock occurs. Above this town the water flows steadily seawards throughout the day, while below this place during one part of the day the direction of flow is *up* the river, and during the other *down*. The resultant motion of the waters of the Thames estuary effectually prevents the formation of a delta at the river's mouth, though there is a continual but irregular deposition farther out at sea, leading

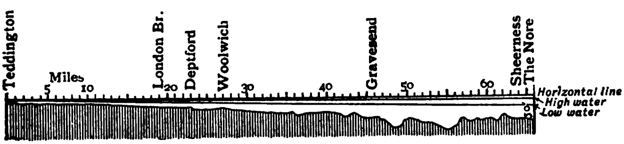


FIG. 91.—To show the decrease in tidal range on the Thames, between the Nore and Teddington.

to the formation of shoals. Often the retarding effect of the inflowing tide upon the outward movements of the river's water causes a deposit of the nature of a **bar**.

In other cases, especially where the channel is narrow, as in the case of the Severn, the combination of a rapidly rising tide with a swiftly moving river causes the inflowing water to be forced up to a considerable height, constituting a **bore**.

Bores.—The conditions necessary for the formation of a bore appear to be three in number.

(1) A swiftly flowing river.

(2) An extensive bar of sand, dry at low water, except in certain narrow channels kept open by the outgoing stream.

(3) The estuary into which the river discharges must be funnel shaped, with its wide mouth open to receive the tidal wave from the ocean. In the Thames only the third of these conditions holds true, and no bore results. In the Severn they are all present, and hence a bore occurs.

In the case of the **Tsien-tang-Kiang** all three of the conditions are present. "The range of the tide immediately outside the Hang-chan gulf is twelve feet; but as the wave becomes compressed on advancing towards its head, at the end of the navigable waters, it is as much as twenty-five feet at ordinary spring-tide, and

thirty-four feet when the wind is blowing on shore and the moon in perigee at the time of full and change." *

The tidal waves run squarely between the shores of Nova Scotia on one side and the States of Maine and New Brunswick on the other, and the narrowing form of the course causes the tides to be exceptionally high. The greatest tide-range in any part of the Bay of Fundy is at Noel Head, in Cobequid Bay, where the difference between high and low water mark reaches fifty-three feet. The **Petitcodiac River** flows into the head of the bay, and it is on this river that the famous bore is seen. It rushes up the river as a foaming breaker five or six feet high, with a velocity of six or seven miles an hour.

Bore of the Severn.—This well-known bore can be seen very satisfactorily at Newnham. The whole time occupied by the rise of the tide is an hour and a half, and the rise at this place amounts to eighteen feet. The large tide rising with so marked a rapidity produces the bore, which is increased in amount by the fact that the river is here bordered with a stretch of flat sand near the level of low water.

19. GLACIERS.

1. Ice lighter than water.—Put a block of ice, if possible rectangular in shape, into water, and estimate what proportion of the block is submerged. If the block is rectangular, the proportion may be found with fair accuracy by help of a pair of dividers, or even a graduated rule. From your measurements, what do you conclude as to the weight of a piece of ice compared with the weight of the same volume of water. Calculate the size of the ice produced when one cubic foot of water freezes.

FIG. 92.—Ice is lighter than water.

2. Regelation.—(*a*) Press two blocks of ice together. What is the result?

(*b*) Support a block of ice between two stools, and suspend from it a heavy weight attached to a wire. Notice, as the wire gradually cuts its way through the block, whether the pieces produced remain separate or become united again above the wire.

(*c*) (*Outdoor work.*)—In frosty weather fix a straight icicle by one end in a horizontal position, leaving the rest of its length unsupported.

* *The Bore of the Tsien-tang-Kiang.* By Commander W. W. Moore. Institution of Civil Engineers, vol. xcix.

Describe any changes in the shape of the icicle. Treat a stick of sealing wax in the same manner and compare the results.

(*d*) Fill an empty stone ginger-beer bottle with snow. Put a stick through the bottle neck and hammer it in, so as to force the snow into as little space as possible. Take out the stick, put in more snow, and again hammer. Repeat until you have put in all the snow the bottle will hold, even under pressure. Now break the bottle and examine its contents. By what means can snow be turned into solid ice?

3. Signs of former glacial action (*Outdoor work*).—Visit the nearest museum and study any glacier-scratched stones exhibited in it. Note the localities from which the stones were obtained and visit them at the first opportunity; observe the direction of any similar scratches found *in situ*; look for the other signs of glacial action described on pp. 162 and 163, and obtain photographs of any found. Make notes of any erratic blocks in your district, with particulars of the kind of rock of which they are composed, the

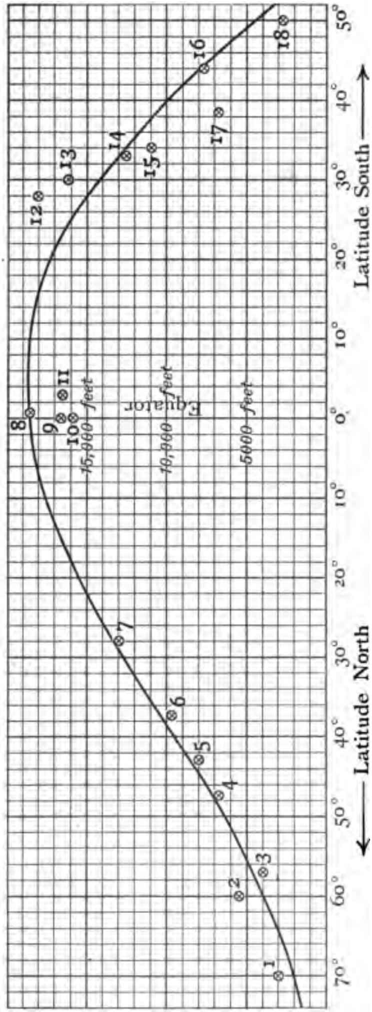


FIG. 93.—Diagram showing height of snow-line in various latitudes. 1, Lapland; 2, Alaska; 3, Ben Nevis; 4, Tauern (E. Alps); 5, Pic du Midi (Pyrenees); 6, Mt. Etna; 7, Himalayas, south side; 8, Bolivian Andes, west side; 9, Andes at Quito; 10, Bolivian Andes, east side; 11, Kilima Njaro; 12, 13, 14, 15, 17, 18, Andes (Chile); 16, Alps (New Zealand).

place from which they were probably brought by glaciers, and any other details you may be able to obtain from local geologists. Study the geological map of your district and see whether glacial drift is marked on it; if so, try to find specimens of the drift and make notes of its nature.

Snow-line.—Above a certain height on a lofty mountain the snow never melts. The line above which snow always exists is called the **snow-line**. As might be expected, it is highest in equatorial regions, falling at last to the sea level as the poles are approached. The height of the snow-line does not, however, vary regularly with the latitude, as is clearly shown in Fig. 93. Temperature is the factor of greatest importance, but its influence is modified considerably by the *amount of snowfall*, as well as by other circumstances.* The diagram shows, incidentally, that in the southern hemisphere the snow-line reaches sea level in lower latitudes than in the northern hemisphere.

Glaciers.—It is from the snow above the snow-line that glaciers are derived. The continual accumulation of snow naturally subjects that at the bottom of the heaps to great pressure, which eventually changes the character of the accumulation completely. As the snow becomes more and more pressed upon by the weight of the overlying masses, it loses its granular nature. The particles gradually cohere, forming a firmer mass, called **nevé** or **firn**, which represents the intermediate stage between snow and ice. Finally, the increased pressure lower in the mass causes the formation of a compact blue ice which slowly moves down the mountain slope as a glacier.

It is not difficult to understand why such a movement of the glacier should take place when it is remembered that the whole process occurs on the slope of a mountain down which any mass would naturally fall if free to move. It is true that the force of adhesion between the ice and sides of the valley has to be overcome, but the force from behind, caused by the weight of the ever-increasing mass of snow, is great enough to overcome this adhesion.

Glaciers are rivers of ice.—Just as rivers can be looked upon as the drainage of the rainfall in a district, so glaciers may be

* The formation of snow is described in Chapter XIII.

regarded as a system of drainage by which the snow-fall above the snow-line is removed. But the similarity between the two does not end here. Glaciers move from high levels to lower in the same manner as rivers, though, as they are much less fluid, the rate of movement is very much smaller. Whereas the rate of flow of a moderately quick river is about 1½ miles per hour,

FIG. 94.—Glaciers descending from snowfields on Mont Blanc, seen from the Brévent. (From Sir A. Geikie's *Text Book of Geology*.)

and of a torrent about 18 or 20 miles in the same time, a glacier moves only a few feet or inches in a day. Thus, the Mer de Glace near Chamonix has an average rate per day throughout the summer and autumn of 20 to 27 inches in the centre, and from 13 to 19½ inches near the sides. The glaciers of Greenland are more rapid, however; that of Jacobshavn on the west coast has a rate varying from 48 to 75 feet in the 24 hours. The difference in the rate of motion of the glacier at the centre

and at the sides was observed by Tyndall in the case of the Mer de Glace, and is characteristic of glaciers, and constitutes another likeness between them and rivers (p. 135). In both cases where the friction to be overcome is greatest the velocity is least, and clearly this is at the bottom and sides.

Proofs of a glacier's motion.—This variation in the motion of different parts of the glacier can be demonstrated in the following ways:

(1) The fissures (crevasses) across the glacier are curved, the curve being convex towards the valley-mouth.

(2) The heap of debris at the foot of the glacier (terminal moraine) assumes the same horse-shoe form.

(3) If a row of stakes be driven into a glacier in a straight line, after a time the middle stakes will be seen to have travelled further down the valley than those at the sides.

Behaviour of glaciers in moving downwards.—The exact causes producing the movement of a glacier cannot be said to be known fully. It has been suggested that ice behaves as a very viscous liquid, and slowly flows down the valley; but others maintain that a continual melting and breaking of the ice goes on, which is followed by the freezing together, or **regelation**, of the separated parts, and that this is sufficient to account for the small amount of yielding experienced.

When a glacier moves valleywards, it has sometimes to travel over a very uneven floor, and some part may get wedged up against an outstanding projection and be prevented from moving; while the upper parts, being still acted upon by the weight of the accumulated snows above, and being free to move, slide over the impaled portion. This will interfere with the regular movement of the glacier, producing something comparable to an eddy in a river.

A sudden drop in the slope of the mountain side, which would in the case of a river produce a waterfall, may cause a break in the glacier. This fissure may in the first instance be nothing more than a crack, but the onward passage of the lower portions will result by-and-by in the formation of a wide gap known as a **crevasse**. These crevasses sometimes reach quite to the bottom of the glacier, but whether they do so or not, there is always

a tendency for the pressure, which acts on all sides, to efface the rent.

The glacier will continue its existence and downward motion until the temperature becomes high enough to melt the ice, when it will give place to a stream of muddy water, which may be the source of a river. It will be evident that a prolonged addition to the snow accumulation towards the summit of the mountain will

Photo. Spooner & Co.

FIG. 95.—The Upper Aletsch Glacier, Switzerland, showing lateral and median moraines.

increase the supply of ice at the valley end, and in that case the amount of heat will of necessity have to be greater to effect the liquefaction of the ice; this increased amount of heat can be obtained lower down only, so that the glacier will become longer. A diminution in the supply of snow will have a contrary effect.

Work done by glaciers is only mechanical.—The mechanical work which a glacier accomplishes is important, and can be considered under two heads—(1) its carrying work; (2) the erosion it effects.

The work of transport is performed in a different way from that of rivers, for most of the detritus is carried upon the surface of the glacier. The ice cannot, like water, hold material in suspension, though frozen into its mass will be the fragments of rock which were mixed with the snow from which it was formed. Corresponding to the larger materials which are pushed along the bed of a river, there is in the case of the glacier a certain amount of detritus at the bottom which has for the most part got there by tumbling down crevasses. The rock fragments which accumulate on the surface of a glacier are known as **moraine** stuff; this is not distributed irregularly, but arranged more or less definitely along the sides and middle, constituting **lateral** and **median moraines** respectively. The median moraines are the result of the union of two glaciers, for when this takes place the right of one and the left lateral moraine of the other unite to form a larger single median moraine. Should a glacier receive several tributaries there will be more than one median moraine formed, the number indicating the number of tributaries received (Fig. 95).

In travelling over uneven ground there will be a tendency for the detritus, which has reached the bottom through the crevasses, to accumulate in places where projections occur. These accumulations constitute what are termed **moraines profondes.**

If for any cause a diminution in the volume of a glacier takes place, some part of the lateral moraine will be deposited on the side of the valley. This deposit often contains blocks of some size, and when these are left in such a stranded position they are spoken of as **perched blocks** or **erratics.** During what is called the **glacial epoch** of geological time glaciers were much more widespread over Northern Europe than they now are, and it is common in some countries to meet with perched blocks far removed from any existing glacier, but without doubt deposited in this manner.

Material deposited by glaciers is known as **glacial drift.**

Glacier tables.—The ice at the surface of a glacier is disappearing continually both by melting and by evaporation. A mass of rock upon the surface of the glacier, however, will protect the ice under it from the heat of the sun. The result is that a pillar of ice, capped with the protecting rock, is often left standing above

the general level of the glacier; this formation is spoken of as a **glacier table.** The pillar of ice slowly disappears and eventually becomes too frail to support the rock, which falls.

A glacier's work of erosion.—The earth and stones which often find their way down crevasses to the bottom of a glacier become frozen firmly into its mass, and as the glacier moves slowly down the mountain side the rock fragments are ground against the rocky bed, becoming themselves characteristically smoothed and scratched, and also causing the same result upon the beds over which they pass. This polishing effect is so great that even the hardest rocks become grooved and striated. The motion of the

FIG. 96.—Glacial striations at Kingston, Ohio.

glacier being generally regularly downwards, these scratches usually indicate the line of motion, and stretch lengthwise down the valley (Fig. 96).

When by a general increase of temperature the glacier as a whole melts, its bed may be seen to have assumed the form of smooth undulating prominences. These rounded mounds are called **roches moutonnées** (Fig. 97) from their fancied resemblance to a well-dressed fleece or one of the wigs formerly styled *moutonnées* (Prof. G. A. J. Cole).

The water formed from the local melting of a glacier collects on the surface, but often finds its way down one of the numerous crevasses, carrying with it a considerable quantity of the moraine detritus. This water finally gets under the glacier, and in many cases, by the help of the stones it carries with it, forms a **glacier-**

mill, which in time erodes a **pot-hole**, or **giant's kettle**. As in the case of rivers, the largest amount of erosion will be effected in those cases where the rocks are soft. It is sometimes indeed sufficiently extensive to form considerable hollows, which on the retirement of the glacier often become filled with water, forming *tarns* or *lakes* (p. 240).

Results of glacial action.—It is quite possible to tell where

FIG. 97.—*Roches moutonnées* at Capel Curig. (From a photograph by Mr. C. J. Watson.)

glaciers have been from the permanent record they leave behind. It will be useful to summarise the evidence, the existence of which in any country can be taken as proof of the previous existence of glaciers.

(1) Glaciated **hills** are **rounded** (Fig. 98), in contrast with the irregular outlines of peaks in the sculpturing of which glaciers have not taken part (Figs. 98 and 99).

(2) Glaciated **valleys** are typically flat-bottomed or **U-shaped** (Fig. 98), whereas valleys formed by rivers only are typically V-shaped (Figs. 16 and 86). A main valley recently deepened by

a glacier is as a rule at a markedly lower level than its tributary valleys (which are therefore called "hanging valleys"); so that tributary streams join the main river by waterfalls from the "shelf" or "shoulder" where the continuity of the slope of the side of the main valley is broken.

(3) The upper end of a recently glaciated valley is frequently distinguished by a flat, "arm-chair"-like area called a *cirque*, *corrie*, *cwm* or *combe*, in which a lake often occurs. The precise mode of formation of a cirque is still rather uncertain.

Photo. Frith & Co.

FIG. 98.—Grasmere. The rounded hills and U-shaped valleys are signs of glacial action. At the head of the lake is an alluvial plain.

(4) The heap of materials (the *terminal moraine*) formed at the glacier's foot where it began to melt. It contains striated stones and is easily recognised.

(5) The smooth glaciated rocks which formed the bed of the glacier are unmistakable. The striations found thereon are more or less parallel, and show the direction of the glacier's flow (Fig. 96).

(6) Perched blocks often occur on what was originally the side of the glacier. They are quite dissimilar in nature from the rocks on which they rest.

(7) The material at the bottom of the glacier (moraine profonde)

is strewn irregularly over the site of the glacier, and contains characteristically marked stones, the mixture of "glacial drift" constituting **boulder clay**.

Icebergs are broken off from glaciers which reach the sea in polar regions.—When a glacier in polar regions reaches the sea level, it moves on into the water, where parts break off and float away as **icebergs**. Evidently the iceberg is frozen fresh-water and was formed on land. Ice is lighter than water, its specific gravity being

Photo. Frith & Co.

FIG. 99.—The Langdale Pikes. The peaks projected above the level of the ice sheet of the glacial period, and therefore show the irregularities characteristic of unglaciated mountains.

0·918 compared with that of pure water at 4° C. The ice consequently floats upon the water, and as its density is very near that of water, only about one-tenth of the iceberg is above the sea level, the other nine-tenths being below. As the iceberg travels into warmer latitudes it gradually melts, dropping into the sea the materials which were frozen into it when it existed as a glacier. Icebergs are often of a great size, being sometimes several miles in circumference and rising to a height of 700 feet above the water. They are rarely found south of latitude 40° N. or north of latitude 35° S. (Fig. 154).

The Glacial Epoch.—The period at which the glaciers just referred to existed in Britain is known as the Glacial Epoch or the Great Ice Age. The Glacial Epoch occurred quite recently—as a geologist estimates lapse of time, though judged by everyday standards its remoteness is immense—so that the effects which that great event had upon the features of hill and dale have not yet been effaced by denudation. It is quite evident that at that time most of the northern hemisphere was like modern Greenland in being covered by a thick sheet of ice, above which only the summits of the peaks protruded (Fig. 99). The signs of glaciation

FIG. 100.—The formation of icebergs.

detailed above are still to be recognised in almost all parts of the British Isles north of the latitude of the Bristol Channel, and particularly in the hilly areas of the Highlands of Scotland, the Lake District, Wales, etc. Rocks brought by glaciers from Norway are found near Flamborough Head and in the Fen district, and boulders of Ailsa Craig granite occur as far south as the Midland counties of England.

By carefully noting the position of erratics and where possible ascertaining the locality of the parent rocks, and observing also the directions of the glacial striae, geologists have been able to prepare maps showing the centres of glaciation and the movements of the glaciers.

EXERCISES ON CHAPTER VII.

1. Why do some rivers form deltas and others flow into estuaries? Give examples of each.

2. Explain how glaciers are formed. Describe the appearance of an Alpine glacier.

3. (*a*) What is meant by (i) the source of a river, (ii) the bed of a river, (iii) a gorge, and (iv) the right bank of a river?

(*b*) If the bed of a river is made of rounded pebbles, how did they get there, and how is it that they are rounded? (C.P.)

4. Describe carefully how rivers act (i) as denuding agents, (ii) as depositing agents. Illustrate your answer by reference to some one continent whose geography is known to you. (C.P.)

5. What are river terraces, and how are they formed?

6. How do natural springs arise? (C.J.)

7. Rain and rivers do much in the way of land destruction, but they work with far greater effect when aided by the action of frost. How can you prove this statement? Give examples. (L.J.S.)

8. Describe, with diagrams, the various conditions which determine the formation of springs. (C.S.)

9. How are waterfalls formed? (C.J.)

10. Describe shortly conditions which may give rise to a surface spring. (O.J.)

11. What is a bore? Give an example from the British Isles. (C.S.)

12. In relation to a glacier give a description of (*a*) nevé, (*b*), crevasse, (*c*) moraine. (C.J.)

13. Give a short account of the action of rain as an agent of denudation. (C.S.)

14. Describe the effects produced by a river (*a*) in the upper and steeper part of the course, (*b*) in the lower and flatter part. (C.S.)

15. What explanation can you give of the fact that one bank of a river occasionally is sloping while the opposite one is steep-sided? Of which portion of a river valley is this feature most characteristic, and for what reasons? (Prel. Cert.)

16. Trace the course of a typical river from source to mouth, describing the ways in which it might modify the surface of the earth. Illustrate your answer by reference to the rivers of France. (J.B.M.)

17. What is a river? Name the different parts, and give a short description of each.

18. Describe an Alpine glacier. Compare it with the Greenland ice sheet. What evidence is there to show that glacial conditions formerly prevailed in Britain? (L.M.)

19. Give an account, with diagrams, of the structure of the London basin.

Explain how, in some cases, London obtains water from artesian wells. (J.B.M.)

20. Define the following:—*water-shed*, *river-bed*, *river-basin*, *contour lines*, *delta*, *estuary*, *bar*. (N.F.U.)

21. Define *penumbra*, *zenith*, *the glacial period*, *watershed*, *Mercator's projection*. (N.F.U.)

22. Describe how a plateau is reduced by denudation to a plain, and give actual examples of different stages. (J.B.M.)

CHAPTER VIII.

VOLCANOES AND EARTHQUAKES.

20. VOLCANOES AND VOLCANIC ACTION.

1. Distribution of volcanoes.—Examine Fig. 106. Are the volcanoes shown on it scattered irregularly, or do they lie along lines or bands? Are they most abundant near or far from the sea? Compare the borders of the Atlantic and of the Pacific Oceans in respect of the number of volcanoes. How many volcanoes are on islands? Is there any special abundance of volcanoes along mountain ranges?

The internal heat of the earth.—Both volcanoes and earthquakes can be traced to the internal heat of the earth, which may be regarded as the relic of a former molten condition of our planet.* That the interior of the earth is at a much higher temperature than the crust is concluded from such observations as the following:

(*a*) The materials ejected from volcanoes are at a very high temperature. Those substances which are liquid at ordinary temperatures, such as water, are emitted in a gaseous condition. Those which are solid at the temperature of the earth's surface, are often ejected as lava in a liquid state. The inference is that the locality from which they are derived is at a very high temperature.

(*b*) The temperature rises as the centre of the earth is approached. The rate of increase met with in deep mines and borings varies in different places for a variety of reasons, such as the different specific heat and conducting power of the rocks. An

* Recent discoveries suggest that the present internal heat of the earth is due largely to the action of radium and similar radioactive substances.

average result, according to a British Association Committee, is an increase of 1° F. for a descent of 64 feet.

(*c*) The temperature of the waters of artesian wells, hot springs and geysers, is higher than that of surface waters. The temperature of the water of the hot springs at Bath is 120° F., that of some of the geysers of Iceland 190° F.

Definition of a volcano.—A volcano is nothing more than a hole, usually a crack, connecting the exterior and the interior of the earth. The definition still given in some geography books that it is "a burning mountain" is altogether wrong. Of *burning*, in any correct sense of the word, there is none. Nor need a volcano be a mountain. Although the accumulation of the ejected materials round the hole in the crust often causes a hill to be built up, there is sometimes no such mound formed, indeed in some cases there is an actual depression. The definition becomes more complete if we add that from the hole in the crust are ejected, sometimes with explosive violence, various materials, which are generally at a high temperature. Our definition thus becomes:

A volcano is a hole, usually a crack, connecting the exterior and interior of the earth; from it are ejected, often with explosive violence, various materials, which are generally at a high temperature.

Kinds of volcanoes.—Volcanoes may be divided into classes depending upon the frequency of the eruptions which take place. **Active** volcanoes are those from which an eruption can be expected at any time. If there is no cessation of activity of some degree, we have a *constant* volcano, like Stromboli. If the eruption is followed more or less regularly by a period of rest, such a volcano is called *periodic*, like Vesuvius, where, after a great eruption in 1872, there were only disturbances of minor importance until the next great eruption in 1906. If the period of rest extends into a great number of years, and is then followed by an eruption, the volcano is described as **dormant**; and in those cases where the activity seems to have ceased altogether, we have **extinct** volcanoes.

Materials ejected from volcanoes can be classed under three heads, according to the physical condition in which they are emitted, viz. *gaseous*, *liquid*, *solid*.

The chief **gas** given off from a volcano is *steam*. This vapour is evolved in enormous quantities. The air round the volcano

becomes so saturated with moisture that the steam accumulates as clouds of great extent, and is condensed into torrents of rain.

In addition to steam, there are also emitted *carbon dioxide*, *sulphur dioxide*, *hydrochloric acid gas*, with others, though in very small quantities only.

The **liquid** material which is given off by a volcano is known as **lava**. Its degree of fluidity depends upon its chemical composition. The rate at which this liquid lava cools is generally slow. The top of the stream cools very slowly after a thin crust, which looks

FIG. 101.—Nicolosi, Etna. Common scoriaceous lava. (From a photograph by Dr. Tempest Anderson.)

like a clinker, has once been formed. When lava cools quickly, a glassy rock, like *obsidian*, is the result. The flow of the liquid lava below, after a crust has formed on the surface, causes the characteristic "corded" appearance shown in Fig. 104. Steam is given off in cooling, and this gas in escaping often causes the lava to be filled with holes and gives rise to a *vesicular* rock.

Pumice is formed by the expansive force of steam inside acid lavas. From the cindery appearance (Fig. 101) which some cooled lava streams have, the term *scoriaceous* has been derived, and is often used to describe the volcanic rocks so formed. Lavas

sometimes take a beautiful columnar form on cooling, like the basalt columns of the Giants' Causeway and Fingal's Cave. This columnar structure is shown in Fig. 102.

Fig. 102.—Ordinary columnar structure of basalt (Giants' Causeway).

The **solid** materials ejected from volcanoes are usually of a fragmental kind. They include bombs, lapilli, and dust. *Bombs* are lumps of lava forced off the ascending liquid column by the current of issuing steam. They are whirled round and round in the air, and get a roughly spherical form. They cool rapidly on the outside into a glassy shell, but inside are much more crystalline. *Lapilli* are angular fragments of lava similarly forced off by the issuing steam. The larger pieces are known as *scoriæ*, the term lapilli being reserved for pieces varying from the size of a pea to that of a marble.

Cause of volcanic action.—Volcanic action is probably the result of several causes, all of which are responsible to some extent for the effects to be described below. Until quite recently explosions caused by superheated steam were regarded as of much the greatest importance. From the bottom of the sea and lakes, from the surface of the land everywhere, water is passing continually into the crust of the earth. This percolation goes on through every crevice. Sometimes by its own weight, and often when the cracks are only minute, by capillary attraction, an enormous amount of water must reach the interior. But whether such water really reaches highly heated rocks seems questionable. Whatever its source, water is present in most lavas, and must be converted into steam as the lava approaches the surface. The temperature will be much higher than the boiling point of water at the sea level, because the pressure to which the water is subjected in the earth's interior is very great. Steam will be formed continuously, and thus there will be more and more vapour forced into a given space, which will cause the pressure of the

steam to become greater and greater. Just as in a boiler the pressure of the enclosed steam can only be increased safely up to a certain point, beyond which a further addition to the pressure will cause the material of the boiler to break, resulting in an explosion, so the pressure of the steam enclosed within the earth's crust can only go on without an explosion so long as the pressure of the steam upwards is less than that of the weight of the rocks downwards. When the pressure of the steam is increased beyond this point, a **volcanic eruption** takes place. Either a new crack is formed in the earth's crust through which volcanic materials are ejected, or the solidified lava in an old volcanic vent is forced out violently and a new eruption takes place from an old volcano.

A full explanation of volcanic action, however, is not yet available. Volcanoes occur in marked abundance along certain great lines of folding of the earth's crust, and on the margins of regions which show signs of recent elevation or depression. This fact confirms a theory that the subterranean movements and ultimate ejection of molten matter are due to the crumpling and rearrangement of the rock masses. The lava naturally takes the path of least resistance, which is often a volcano already in existence.

A volcanic eruption.—The order of events throughout a volcanic eruption is by no means uniform, but there are many phenomena which generally occur. In the eruption, as we shall describe it, no particular instance is referred to, but the chief events are narrated in the order in which they would probably happen. When the neighbourhood has been quiescent for some time, the advent of a new disturbance is heralded generally by loud rumbling noises from the earth's interior, which are often followed by earthquake shocks (p. 181). There may be at this time, too, a fairly universal interference with the direction and nature of the streams, as well as of the sea level, in the neighbourhood.

These premonitory signs last for varying periods, and are followed by an increase in the amount of steam which escapes from volcanic vents in the district, as well as by a raising of the level of the lava in the throat of such vents. Then a mighty explosion takes place. There is a sudden and violent escape of a huge volume of pent-up steam. The force with which it issues is so tremendous that it scatters lumps, which it tears from the sides of the throat, in every direction, propelling some of them far up into the air. Cases are on record where the expansive force of the issuing steam has been

so great that the cone accumulated during previous eruptions has been blown into minute fragments. The particles formed in this way constitute the volcanic dust which is given off in great quantities.

The clouds of steam often take the appearance of flames, and are accountable for the popular idea of a volcano. The molten lava which now fills the neck of the volcano is at so high a temperature that it is luminous. The light it emits is reflected from the banks of steam above, and they themselves are transfigured, appearing as blazes of light. The water vapour with which the atmosphere is saturated becomes condensed and falls as torrents of rain. The falling rain brings down with it the volcanic dust, and together these result in the formation of streams of volcanic mud which flow down the side of the cone. The mutual friction of the particles of vapours and dust causes the clouds to become charged electrically, and results in the thunder and lightning which add to the weirdness of the scene.

The showers of scoriae, lapilli, and dust cause a continual addition to the size of the cone. The dust, too, in the presence of winds, is carried huge distances, sometimes many thousands of miles. An example was afforded by the eruption of Krakatoa in August, 1883, when the dust was carried from the Malay Archipelago as far as England, its influence here being seen in the gorgeous sunsets to which it gave rise. Finally, we must mention the streams of lava which begin to flow when the liquid rocks from the interior well over the sides of the crater's mouth.

The events of the eruptions in the West Indies, those of the Soufrière mountain in St. Vincent, of Mont Pelée in Martinique, which took place from May to July, 1902, and of Matavanu in Savaii (Samoa), which began on August 4, 1905, differ in some respects from those outlined above. In the case of **the Mont Pelée eruption** (Fig. 103), the most peculiar feature was the avalanche of incandescent sand and the great black cloud which accompanied it. The preliminary stages consisted of outbursts of steam, fine dust, stones, and torrents of water, which had collected in the crater. As soon as the throat of the crater was cleared and the climax of the eruption was reached, a mass of incandescent lava was blown to pieces by the expansion of the gases it contained,

and descended upon the surrounding country as an avalanche of red-hot dust. The torrent of red-hot dust rushed down the slopes of the hill, behaving like a liquid, carrying with it a terrific blast, which mowed down everything in its path, till it reached the sea,

Photo. Underwood & Underwood.

FIG. 103.—Eruption of volcanic dust from Mont Pelée in June, 1902.

when it subsided quietly. The gases were chiefly steam and sulphurous acid; there was little oxygen in the gaseous mixture, and respiration in the neighbourhood was impossible.

In a paper by Dr. Tempest Anderson, read before the Geological Society on April 13, 1910, **the eruption of Matavanu (Samoa)** is described in detail. Before the commencement of the eruption, on August 4, 1905, the place where the cone now is was

an almost level, elevated plain surrounded by mountains. The cone does not rise high above the surrounding lava fields (Fig. 104); only at certain points does it reach a height of 350 feet above them. The bottom of the crater "is entirely occupied by a lake of liquid lava all in rapid motion and of such extreme fluidity that it continually beats in surging waves against the walls, where splashes retain their heat and brilliant colour for some time. The surface is in a constant state of ebullition, though not always to the same degree in different parts. Some of the boilings

FIG. 104.—Common corded lava from the volcano Matavanu. (From a photograph by Dr. Tempest Anderson.) Dr. Anderson points out that the apparently light colour of the lava in the background is due to reflection, the lava being in reality almost black.

rise in veritable fountains of incandescent liquid basalt of 10, 20, or even, I think, possibly at times, 50 feet high. The whole mass of the lava is at a brilliant white heat, visible as such even in bright sunlight, but a darker scum is continually forming on the surface, especially where the trade wind blows strongly on it." The molten lava reached the sea on December 7, 1905, and had been flowing into the sea, with the exception of one day, since that date. Where the discharges into the sea were most active, "explosions were almost continuous, and the whole was obscured by clouds of steam, from which fragments of red-hot lava and showers of black sand were seen to fall. When the lava was

flowing in smaller quantity, explosions were much less noticeable, and the lava extended itself into buds or lobes" (pillow lava). Dr. Anderson pointed out that both Matavanu and Kilauea (in Hawaii) "are of the effusive type, that is, characterised by the discharge of lava very slightly charged with steam and other volcanic gases, and hence little subject to explosive action; in which respect they contrast strongly with the volcanoes of the West Indies and Central America, where most of the recent eruptions have been highly explosive, and attended with the discharge of a vast quantity of ashes, lapilli and pumice, but little or no lava." *

Different kinds of cones.—Cones may be described under four heads, viz.:

(1) *Scoriæ* or *cinder cones.*
(2) *Tuff cones.*
(3) *Lava cones.*
(4) *Compound cones.*

The plan on which they are all constructed follows the same lines, and it will be desirable first to refer briefly to the *structure of a cone* in general. The materials from which the cone is built up are thrown out from a crack in the crust, which must be regarded as the starting point. These fragments severally describe curves, after the pattern of those of the drops of water from a fountain. In this way a circular deposit of ejected material is formed round the orifice as a centre. As the eruption continues, this heap of fragments increases in height, and the mound slopes towards and from the hole at an angle depending upon the nature of the materials. This angle is called the "angle of rest." Eventually the inner slopes close in towards one another, and from the outside the appearance is that of a simple conical hill. If, however, by any means the internal structure becomes revealed, it is seen that on every side of the orifice there is a hill, the sides of which respectively slope towards and away from the vent (Fig. 105).

Cinder cones are made of scoriae or lapilli. These are usually of a dark colour, which becomes changed to a reddish hue by the action of the rain upon the minerals they contain. Though, from the loose nature of the materials of which such cones are built, it might be expected they would be washed away by the rain easily, yet as the extinct cinder cones of Auvergne show, such is not the case. These cones do in time become covered with a soil, but this does not destroy their form. The angle of slope of this order of cone is from 35°–40°, this being the "angle of rest" of such

* *Quarterly Journal of the Geological Society*, November, 1910.

material as scoriæ. These cones are generally higher on one side, which side indicates the direction in which the wind was blowing at the time of the eruption. One kind of scoriæ cone is made of *pumice*, as that of Campo Bianco, in the island of Lipari.

Tuff cones.—Tuff is the solidified volcanic mud the formation of which has been described. The angle of slope of these cones is much smaller than in the previous kind. It varies from 15° to 30°. Their internal character is the same as that of cinder cones. Their colour is much lighter. These cones eventually become impervious to water. The crevices become filled with the results of the decomposition of the materials contained in the tuffs. If such a cone becomes filled with water, a lake is formed like some in the north of Italy.

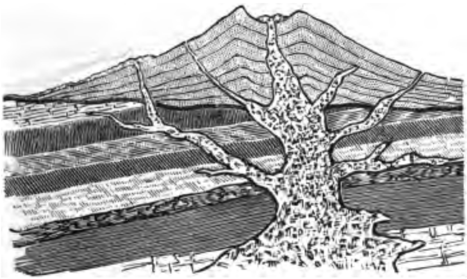


FIG. 105.—Section of a volcanic cone.

Lava cones.—The form of these depends upon the degree of liquidity of the lava from which they are formed. Viscid lavas form steep cones. Very fluid lavas give rise to cones with a gentle slope (Fig. 104). The gradual inclination of the sides of the lava cones at Hawaii also is due to the great liquidity of the lavas found there.

Compound cones are those partaking of the characters of all or some of those described. They are built partly of scoriæ, partly of tuffs, and in some parts of lava. The larger number of cones are of this compound nature. The variable materials of which the cone is built cause it to assume beautifully curved forms as the "angle of rest" of one material gives place to that of another. After a cone has reached a certain height it often happens that the force of the enclosed steam, to which eruptions are due, is insufficient to force the lava high enough for it to flow over the neck of the cone. In such cases the molten rock is forced

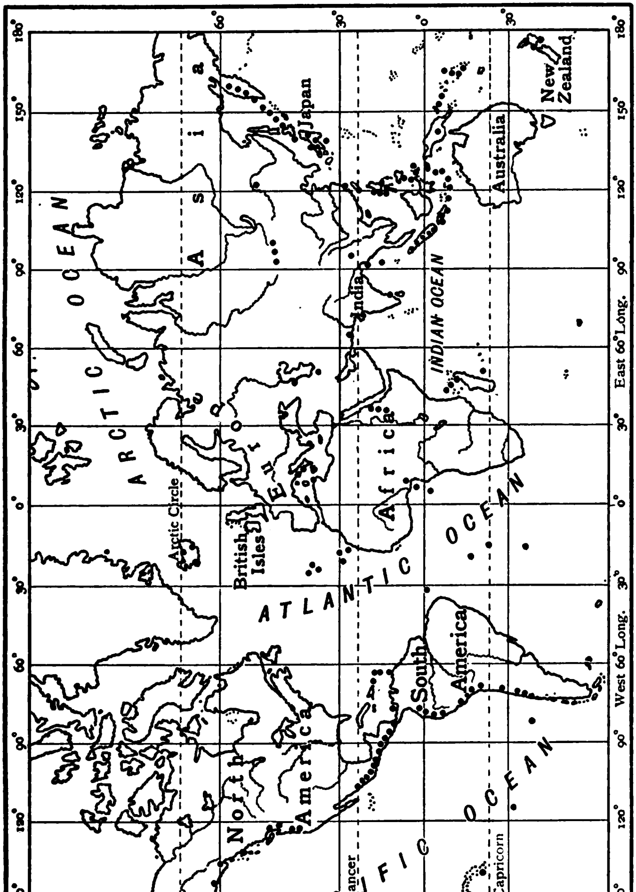
through an opening made in the side of the cone. Often round such secondary necks new smaller cones are formed which constitute **parasitical cones.**

Distribution of volcanoes.—Volcanoes generally occur arranged in lines. The formation of mountain ranges along lines of weakness, or lines of depression, in the earth's crust will be mentioned in Chapter IX. There can be little doubt that the arrangement of volcanoes on lines is evidence of long lines of fissures, or cracks, penetrating the earth's crust. In place of the thickening of the crust along the line of weakness, as in the formation of a mountain range of the ordinary type, there is here a fissure penetrating to deep-seated sources of molten material, which is forcibly ejected by the weight of the overlying rocks, and reaching the surface presents the phenomena of volcanic action. This *linear arrangement* is very marked along the coasts round the Pacific Ocean. Many important active volcanoes, however, are found upon islands. The line which is followed by the volcanic activity on the earth can be traced, beginning from the most southerly limit of America, up the western coast of South America following the line of the Andes, through Central America along the west coast of the northern half of America, by way of the Rocky Mountains, into the Aleutian Islands. Thence it passes by way of the Kurile Islands and Japan, all down the eastern coast of Asia, as far as the Malay Archipelago. Here the line divides, one branch passes in a north-westerly direction to Java and Sumatra; the other turns south-eastwards through New Guinea and passes on to New Zealand.

The line of volcanic activity is not so marked in the Atlantic Ocean. It can be traced from Jan Mayen, through several islands, Iceland, Azores, Ascension, St. Helena, to the West Indies. Nearer home there is a well-marked line in the Mediterranean Sea along which Stromboli, Vesuvius, and Etna lie.

Other forms of volcanic activity.—These phenomena can be traced to the same general causes as those which result in volcanoes. They include **geysers, mud volcanoes,** and **solfataras.**

Geysers.—The name "geyser" is derived from an Icelandic word, meaning a "roarer." Geysers consist of fountains of hot water, which are intermittently active. Huge quantities of hot



Emery Walker sc.

FIG. 106.—The approximate distribution of active volcanoes.

water and steam are forced up suddenly to a great height, and the eruption is followed by a period of rest.

In the case of the "Old Faithful" geyser, in the Yellowstone Park of Wyoming (Fig. 107), this period of rest is nearly always of about 63 minutes duration. In this remarkable district of the United States a large number of geysers occur, scattered over a wide area; and among them are found, from place to place, pools of hot water, which though boiling in some parts are never projected into the air. It is usual to refer to these pools as *hot-springs*, keeping the expression "geyser" for those in an eruptive state of activity.

Fig. 107.—"Old Faithful" geyser in action.

Geysers really only differ from volcanoes in the absence of fragments and molten rock; they mark a declining stage in volcanic action.

Though there are often so many geysers in the same neighbourhood, as in the Yellowstone Park, they are independent of one another, as was observed by Sir Archibald Geikie in this locality. He remarked that "it seemed to make no difference in the height or tranquillity of one of the quietly boiling cauldrons, when an active projection of steam and water was going on from a neighbouring vent on the same gentle slope."

The mode of formation of a geyser is well shown by an ingenious model designed by Bunsen. A column of water is heated in one part by a fire suitably situated. This heating gives rise to the development of a quantity of steam, which by its expansive force, at the moment the pressure becomes high enough, forces all the water above it into the air to a height depending upon the extent of such pressure.

Geysers are common in Iceland, the Yellowstone Park of the United States, New Zealand, and other places.

Mud volcanoes, or *salses*, are formed in those cases where the geyser is active through beds of a clayey nature. When this is the case, instead of comparatively clear water being erupted, mud is given off, from which small cones are formed. They are found in Iceland, Java, etc.

Solfataras.—If only steam and other gases are evolved from a vent in a region of volcanic activity what is called a *fumarole* is formed, and if sulphur vapours are present in large quantities among such gases it is known as a **solfatara.**

Volcanic activity and subsidence.—As evidence of the connection between volcanic activity and movements of the earth's crust may be cited the well-known case of the activity of Vesuvius and the volcanoes in the Phlegræan fields and the elevations and subsidences undergone by the so-called "Temple of Serapis" on the shores of the Bay of Naples. Elevation above and subsidence below the sea have several times taken place in this district, as shown by the marks left upon the upright columns of the Temple still standing. Lyell, by a comparison of dates, showed that while Vesuvius was in eruption the Temple was subsiding and the volcanoes in the Phlegræan fields were quiescent. When, on the other hand, the latter were active, and particularly when Monte Nuovo was formed (1538), the Temple was slowly rising from the waves. Vesuvius has lately been in an active state, and the Temple is high and dry above the sea, but sinking.

21. EARTHQUAKES.

Their nature.—An earthquake is the result of a *sudden* disturbance in the earth's crust. The depth of origin is, in the case of recorded earthquakes, probably not greater than 15 miles. Of only a small proportion of earthquakes has the cause been traced; in the majority of cases no satisfactory explanation has been offered, and it seems likely that most earthquakes are due to forces not yet known. In those cases, however, where the nature of the disturbance appears most definite, it has been found to be either of **volcanic** origin, or to be caused by sudden **dislocations**—often slipping movements—of great masses of rock.

Dislocations of a similar nature sometimes take place gradually. Whether the disturbance is brought about suddenly, giving rise to an earthquake, or is accomplished by imperceptible degrees,

evidence of the process remains in the resulting **fault** in the rocks (Fig. 108), where layers, obviously once continuous, occur at different levels on the two sides of the separating surface.

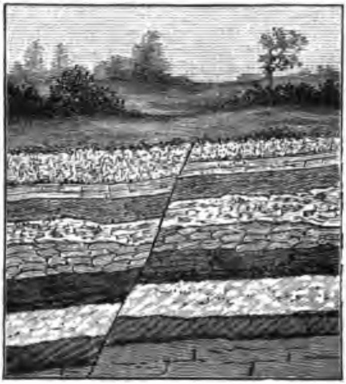


FIG. 108.—Section through a simple fault.

Whatever its nature, the original impulse of an earthquake causes the particles in its neighbourhood to be displaced violently, and by virtue of the elasticity of the rock this displacement is transferred from one particle to the next in every direction. Crust movements are going on continually. The slight ones, which are all that happen normally, are called **earth tremors**. These are brought about by every slight disturbance of the crust, such as may be caused by quivering of the rapidly rotating earth, by winds, and perhaps by the impact of waves on the seashore.

Earthquakes are violent tremors.—The earthquake is propagated outwards from the place of disturbance, called the *seismic centre*, in every direction. A position on the surface of the earth, vertically above the seismic centre, is called the *epicentre*. When the earthquake disturbance reaches the surface of the earth, it is felt as an obliquely up-and-down movement, and anything which is of an unstable nature is unable to resist this motion, and falls. This is particularly the case with chimneys, steeples, obelisks, and so on. For this reason the houses in Japan—where earthquake shocks are very common—are constructed of light and pliable materials like bamboo and paper, which are able to stand the movements without fracture. Darwin remarked, when in South America, that it was a common thing for this up-and-down movement of the crust to cause the trees to dip, and recover themselves, as the shock passed under them. The extent to which the ground is actually moved, even in destructive earthquakes, is surprisingly small. On soft ground near the epicentre the movement may amount to a foot or more, but on hard rock

it is probably never more than 2 inches, according to Major Dutton. A movement of $\frac{3}{4}$ of an inch, occurring in a quarter of a second, is sufficient to cause wholesale destruction.

Types of earthquakes.—Earthquakes of **volcanic** origin are often very violent at and near the epicentre, but do not usually make themselves felt at great distances, because the seismic centre is comparatively near the surface. Earthquakes due to **dislocation**, on the other hand, are felt over a greater area, and are much more destructive in effect. They are always followed by smaller quakes called *after-shocks*, which may succeed each other for days or longer. In dislocation quakes the epicentre is not a point, but a line or area which is often of considerable extent.

Water-waves. An earthquake near or under the sea is often accompanied by a sudden displacement of the bed of the sea. This gives rise to a wave in the ocean. Ships happening to be in deep water are only subjected to an up-and-down movement. As the wave passes into shallow water it naturally increases in height and becomes fearfully destructive. Breaking, it changes

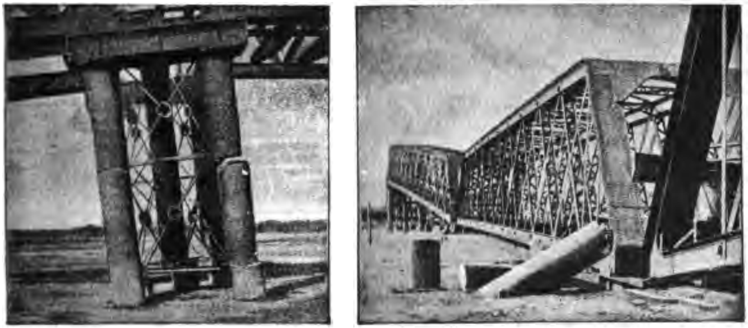


FIG. 109.—Damage done to a railway bridge at Nagara, Japan, during the great earthquake of October, 1891.

the character of its motion. The water as a whole is carried forward, and rushes on to the land with terrific violence, causing locally, as at Lisbon in 1755 and Messina in 1908, great damage and loss of life. A submarine earthquake, the sensible effect of which is confined to sea waves, may be called a **sea-quake**.

The Messina-Reggio earthquake.—The most disastrous earthquake recorded in history occurred on December 28, 1908, in the

district of Sicily and South Italy, when the towns of Reggio and Messina were almost completely destroyed. The disaster was preceded by torrential rain. The shock lasted 37 seconds, and in that short time wrecked the whole province of Calabria and caused the death of thousands of people. The chief centre of the disturbance seems to have been beneath the sea, in Messina Strait, and the cause the sudden formation of a crack in the earth's

FIG. 110.—Messina-Reggio earthquake of December 28, 1908. A wrecked house on Via Porta Imperiale, Messina. The clock on the corner post indicates the time of occurrence of the earthquake, 5.20 a.m. (From the *Bulletin of the Imperial Earthquake Investigation Committee, Tokyo, November*, 1909.)

crust. The earthquake was followed by a destructive sea-wave, which rose to a height of 25 feet, sweeping over the coasts on both sides of the strait.

This sea-wave was evidently caused by a simultaneous sinking of the bottom of the strait through a depth of 3 to 6 feet, as was proved by soundings.*

The whole character of this part of Italy and Sicily has been changed; the level of the sea-shore has been raised, and the

* See *Nature*, vol. 79, p. 288.

interior now presents a twisted appearance with huge fissures in the surface.

Some connection between volcanic activity and this earthquake is suggested by the fact that Stromboli, quiescent before the disturbance at Messina, suffered an eruption some six days afterwards.

San Francisco earthquakes.—The peninsula of San Francisco shows very clearly a close association of earthquake activity and the readjustment of rock masses. More than 200 earthquakes

Photo. G. K. Gilbert.

FIG. 111.—Tramway lines buckled by movement of the surface, San Francisco, earthquake of April, 1906. (From *Bulletin* 324, *U.S. Geol. Survey.*)

of varying intensity have occurred here since 1850, and the presence of several lines of faulting, running across country in a north-westerly direction towards the sea, shows that the underlying rocks have been displaced to a very great extent. The origin of Californian earthquakes in general, has, further, been found to be deeply seated. In April, 1906, an earthquake lasting just over a minute wrecked a great part of the city, and a terrible fire which broke out immediately afterwards completed its destruction. Careful measurements have shown that the coast of California, from north to south, is appreciably longer than it was 50 years ago. Indeed, the belief is growing that—contrary to former

theories—expansion of the ground is the usual cause of the break which accompanies a "dislocation quake."

FIG. 112.—Fence parted by horizontal movement along the fault, San Francisco, earthquake of April, 1906. (From *Bulletin* 324, *U.S. Geol. Survey.*)

Distribution of earthquakes.—Slight earth tremors are felt everywhere; but the more violent disturbances which are included under the term earthquakes are much more frequent in some districts than in others.

Major De Montessus de Ballore, a well-known authority on earthquakes, pointed out that earthquakes are most numerous where variations of topographical relief are greatest; and that unstable regions are associated with the great lines of corrugation of the earth's crust. As examples of the truth of this generalisation, Major Dutton mentions * that the profound depth of the ocean (nearly 4000 fathoms) just off the eastern part of the Aleutian Chain is "one of the greatest breeding grounds of world shakers"; also, *à propos* of the great frequency of earthquakes in the West Indies, that the sea bottom in the vicinity of the Greater Antilles is one of the most rugged and highly diversified in its profile of any part of the earth. Again, most Japanese earthquakes "originate in that great slope of the sea bottom which leads down to the Tuscarora Deep" (Figs. 70 and 73).

* Dutton's *Earthquakes in the Light of the New Seismology* (Murray).

Very few earthquakes in the western or northern Pacific are of volcanic origin, and Californian earthquakes as a class also appear, from the depth of their seismic centres, to be caused by dislocation.

The earthquakes of Central America and South Mexico, on the other hand, are very obviously associated with volcanoes (which are more numerous and closely adjacent here than anywhere else in the world) and are found to be of shallow origin.

In the region of the Andes it is probable that both volcanic and dislocation quakes are abundant and intermingled. On the coast of Chile and near the Andes, earthquakes are very common. When they occur in the sea bottom they are noted for great and destructive sea-waves. Major Dutton states that "the great fiery circle" sometimes said to surround the Pacific has no existence in fact, since the earthquake regions round this ocean are so widely separated by areas of repose.

All the great earthquake regions "are with one exception areas in which the sea predominates over the land. The single exception is the long belt of mountainous country bordering on the north of the Mediterranean, including the Italian and Balkan peninsulas, and extending thence eastward through Persia and Turkestan to the Pamirs and Himalayas." *

Seismographs.—Information of the manner in which earthquake shocks are transmitted has been gained chiefly from instruments

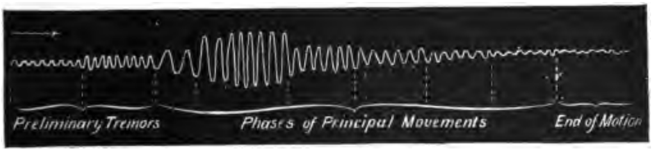


FIG. 113.—Typical diagram of a long-distance seismogram. (Omori.)

which record the movements of the ground. Such instruments are known as seismographs. In principle a **seismograph** is a pen in contact with a sheet of paper moved by clockwork. The pen is so suspended that it remains as nearly as possible at rest, although its supports may be in motion. The paper is connected with the earth, and shares all movements of the ground, so that the pen traces a line which is straight when the earth is undisturbed, but becomes wavy when the earth is shaken. A line of this kind is called a **seismogram** (Figs. 113, 115 and 116).

* *Ibid.*

Horizontal pendulums.—Many very complicated seismographs have been devised, with the objects of obtaining as perfect a "steady point" as possible, of procuring records of motion in any direction, and of magnifying the motion so that all its details may be studied closely. Some of the most important results have been obtained with various forms of horizontal pendulum. In its simplest form, a *horizontal pendulum* is a rigid rod pivoted at one end in such a manner that it can only move in a horizontal plane. In principle it is similar to an ordinary field gate, being supported at one end on pivots or hinges, and free at the other end. If a pendulum of this kind has at its free end a stiff bristle

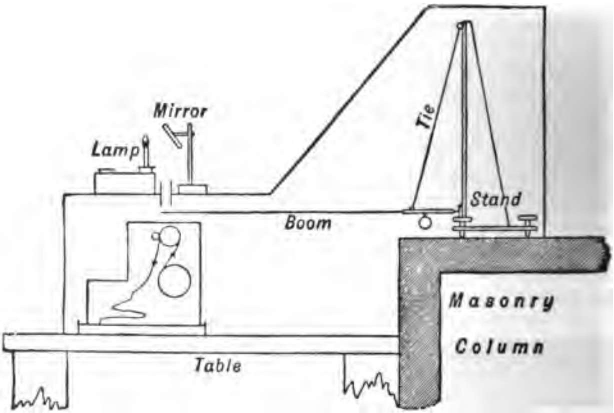


Fig. 114.—Type of horizontal pendulum devised by Prof. Milne, and adopted by the Seismological Investigation Committee of the British Association.

or light pen fixed vertically to it, while its lower end touches a piece of smoked paper, then it is easy to understand that if the surface of the ground shakes to and fro horizontally, owing to earthquake vibrations, the paper is carried to and fro under the pen fixed to the horizontal pendulum and a record of the movement is thus obtained.

The form of horizontal pendulum devised by Prof. Milne to record earthquakes, diurnal waves, tremors and other small earth movements is shown in Fig. 114.* The end of the pendulum near the stand has upon it a vertical point resting in a small agate cup. The rod is supported horizontally by means of the tie of silk thread or quartz fibre shown in the figure. The

* See *Nature*, Jan. 20, 1898.

outer end of the boom of the pendulum carries a small aluminium plate in which there is a slit. This is free to swing to the right or left over a slit in the lid of a box in which clockwork drives a band of photographic paper. Light from a lamp is reflected by a mirror to the two crossed slits, and reaches the paper at a luminous point, which in consequence of the motion of the paper becomes a line on the photographic record. When there are no earth movements, the record is a straight line, but when earthquake waves or tremors disturb the place where the instrument is fixed, the line becomes broken (Fig. 115).

Other important types of horizontal seismographs are those devised by Dr. E. von Rebeur Paschwitz, Dr. Omori, Dr. E. Wiechert, and Prince Boris Galitzin.

FIG. 115.—Long-distance seismogram of the eruption of Mont Pelée (p. 173) on May 8, 1902, obtained by Prof. J. Milne in the Isle of Wight.

Earth waves.—It has been found that the shock of an earthquake is transmitted from the seismic centre to distant points on the earth's surface by three different classes of earth waves. Two —called **longitudinal** and **transverse** waves respectively, from the manner of vibration of the earth particles transmitting them— travel through the *interior* of the earth, in nearly straight lines. The waves of the third kind, known as the **long** waves, travel *along the earth's crust*, approximately along the arcs of great circles, from the centre of disturbance to distant points.

The location of earthquakes.—Though all the waves set up in the earth's crust and core by a particular earthquake disturbance start at the same instant from their place of origin, they do not travel with the same velocities. An important fact which comes out from Prof. Milne's observations is that on every seismogram a number of small movements or tremors are seen before the vibrations due to the long waves, and the duration of these **preliminary tremors** increases according to the distance of the seismograph from the place of origin of the earthquake. It is thus possible to estimate the distance of the place of origin from a given station by observing the duration of the preliminary

tremors recorded by a seismograph before the long waves arrive.

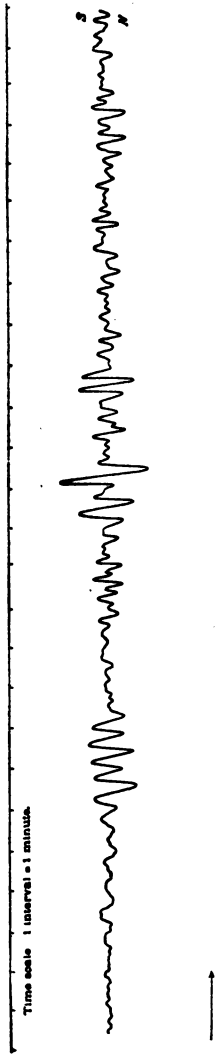


Fig. 116.—Long-distance seismogram of the Messina-Reggio earthquake of December 28, 1908, obtained by Dr. F. Omori in Tokyo. The preliminary tremors commenced at 1 h. 32 m. 8 s. p.m., by 1st Normal Japan time, which is 8 hrs. ahead of Central Europe time. (Compare Fig. 110.) The illustration shows the principal portion of the N.-S. movement magnified 9 times. The arrow shows that the record begins on the left. (From the *Bulletin of the Imperial Earthquake Committee, Tokyo, November*, 1909.)

Thus, in the case of the Messina-Reggio earthquake of December 28, 1908, Dr. F. Omori found that in Tokyo the first preliminary tremor lasted for 11 min. 39 sec., and he calculated from this fact that the distance of the earthquake (measured along an arc of a great circle of the earth) was 9930 kilometres. The actual arcual distance between Tokyo and Messina is about 9900 kilometres.

Again, it was calculated—also from the duration of the first preliminary tremor—that 11 min. 51 sec. must have elapsed between the earthquake and the arrival of the first vibrations at Tokyo at 1 h. 32 m. 8 s. p.m. That is, the earthquake must have taken place at 1 h. 20 m. 17 s. p.m. by 1st Normal Japan time. Since 1st Normal Japan time is 8 hours ahead of Central Europe time (Chapter IV.), this result agrees remarkably well with the actual time (5.20 a.m.) of the earthquake as shown by the stopping of clocks (Fig. 110).

The long waves appear to travel—in great circles along the earth's crust—at a uniform speed of 3·6 kilometres per second. It is therefore possible, from observations of the respective times of arrival of the long waves at three or more widely separated stations, to determine the position of the epicentre of an earthquake. Methods have also recently become possible of finding this point from the record of a single seismograph.

The speed of the waves travelling

through the core of the earth is therefore now known. From it the elasticity of the earth's core has been calculated. It is found from this that the earth as a whole must be at least as rigid as if it were composed wholly of steel. It follows that **the earth's interior cannot be in a molten condition,** or at least cannot have properties like those of any liquid at the earth's surface.

EXERCISES ON CHAPTER VIII.

1. Give a full account of the phenomena (terrestrial and marine) produced by earthquakes. (C.S.)

2. What is a volcano? Write a short description of the usual form and structure of one. (C.J.)

3. What are the principal products given out by an active volcano? Describe the structure of a typical volcanic cone. (C.J.)

4. Describe the effects of an earthquake near a sea coast. What regions of the globe are specially subject to earthquakes? (C.S.)

5. What is a volcano? In what ways does volcanic energy manifest itself? Describe, and show by a map, the principal zones of volcanic action. (N.F.U.)

6. Describe accurately a volcano, both when quiet and when active. Discuss the distribution of volcanoes on the earth. (N.F.U.)

7. Give a brief account of (*a*) the gaseous, (*b*) the liquid, (*c*) the solid materials ejected from volcanoes.

8. What is lava? Describe some of the commonest types.

9. What differences have been noticed in the behaviour of the volcanoes of the Central Pacific and those of the West Indies and Central America?

10. Give an account of any particular volcanic eruption.

11. Write a short essay on the geographical distribution of volcanoes.

12. What is a geological fault? In what manner may such a fault have been formed?

13. What are the known causes of earthquakes? Give two examples of each kind you mention.

14. Explain the terms *seismic centre*, *epicentre*, *seismograph* and *seismogram*.

15. What is the general principle on which a seismograph is constructed?

16. Describe a typical "long distance seismogram" and explain its most important features.

17. Explain generally how (*a*) the distance, (*b*) the position of an earthquake may be determined from the records of seismographs.

18. What light has earthquake study thrown on the condition of the earth's interior?

19. Write a short essay on the geographical distribution of earthquakes.

CHAPTER IX.

THE ORIGIN OF ROCK MASSES.

22. THE FORMATION OF STRATIFIED ROCKS.

1. Examination of chalk and limestone.—Smash pieces of limestone and look carefully for shells or other animal remains among the pieces. Brush a piece of natural chalk (*not* blackboard chalk) with a stiff tooth brush in water, and with a microscope or strong magnifying glass examine the sediment for small shells.

Pour a drop of dilute hydrochloric acid, or strong vinegar, on the chalk, and describe the result.

2. The effect of pressure on mud.—Collect some stiff mud from the bed of a pond or river. Put it in a box and cover it with a board just small enough to go into the box. Put heavy weights on the board, and leave the whole arrangement until the water pressed out has had time to dry up. Examine the dried and compressed mud and compare it with shale.

Test a little shale with acid.

3. The process of infiltration.—(*a*) Put some sand in a dish. Cover it with lime-water. In another dish place some similar sand covered with water. Leave both dishes exposed until the water in each has dried up. Compare the contents of the dishes. Can you suggest any method by which sandstones are formed in nature?

(*b*) Put a small piece of red sandstone in a test tube. Cover it with strong hydrochloric acid, and then put the tube in boiling water until the acid has dissolved the oxide of iron which holds the grains of the sandstone together. Pour off the reddened acid and wash the remaining sand with water. What is the colour of the loose grains of sand?

4. Stratified rocks (*Outdoor work*).—Whenever opportunity occurs examine the exposures of rock in quarries, railway cuttings, etc., and write a description of any rocks arranged in layers, noting the "dip"

or angle which the layer makes with the horizontal, and the point of the compass toward which the layer slopes.

The formation of stratified rocks.—The action of rain, rivers and glaciers has been shown in Chapter VII. to result in the deposition of rock fragments on the bed of the sea, or of lakes. At the time of their deposition almost all such materials are laid down in layers, or **strata**, which are roughly parallel and horizontal. That they are not strictly so is apparent from the most cursory examination. Nor can it be expected that they will be strictly parallel when the conditions of deposition are considered. Imagine a river pouring a quantity of suspended detritus, consisting of mud, sand and gravel, into the quiet waters of a lake; it is clear that the heaviest gravel must be deposited first, and be succeeded by the sand and mud in order, forming a roughly parallel arrangement. Wherever the area over which deposition is taking place is larger, the volume of suspended material greater, and the process of deposition slower, the approach to parallelism is more marked.

In the absence of any disturbance of the strata, those beds which lie beneath must have been deposited before, or are older than, beds occurring above. In this way the geologist arrives at conclusions as to the relative ages of strata.

Main divisions of stratified rocks.—Fig. 117 is a table of the principal groups of stratified rocks, in the order of their deposition (the oldest at the bottom and the youngest at the top), and representing their thickness in Britain on a scale of about 20,000 feet to one inch. Each division possesses characters by which rocks, laid down during the same period of geological time, can be recognised in whatever part of the world they may occur. As is natural, the same name is used to denote both the rocks themselves and the period of time during which they were being deposited. Thus, by the Carboniferous *Period* is meant the interval of time during which rocks of the Carboniferous *System* were being deposited. On Fig. 117 are represented three main **classes** of strata, corresponding to three great **eras** of time: Primary (commonly known as Palaeozoic), Secondary (also called Mesozoic) and Tertiary (or Cainozoic). We are at present living in a fourth era

(the Quaternary), of which the epochs of time which have so far elapsed are known as Pre-glacial, Glacial (p. 165), and Post-glacial respectively. The strata hitherto laid down during the Quaternary era, however, have not attained sufficient thickness to be represented satisfactorily on the scale of Fig. 117.

TERTIARY	
Cretaceous	SECONDARY
Oolite, *Lias* } Jurassic	SECONDARY
Triassic	SECONDARY
Permian	PRIMARY
Coal Measures, *Millstone Grit*, *Carboniferous limestone* } Carboniferous	PRIMARY
Devonian and Old Red Sandstone	PRIMARY
Silurian	PRIMARY
Ordovician	PRIMARY
Cambrian	PRIMARY

FIG. 117.—Simplified table of British stratified rocks. Scale of thickness, about 20,000 feet to one inch.

Hardening of rocks.—The way in which the deposits thrown down in the manner explained above become hardened into the stratified rocks must now be considered. There are two great causes at work bringing about this result, viz., the hardening by **pressure** and that brought about by **infiltration**. By squeezing some mud under a heavy weight, it is seen that the mud becomes drier

and more compact as the weight is increased and the pressure prolonged. The great mass of deposited sediment, which is being added to continually, exerts an enormous downward pressure upon the bottom layers, causing them to become dry and compact.

The process of infiltration can be imitated by pouring lime-water on to some sand contained in a vessel, and then allowing the water to evaporate by placing it in a warm place. The lime dissolved in the water is deposited between the grains of sand, and binds them together as the mortar used by a mason binds the stones of a wall together.

In nature, too, water containing such substances as lime in solution percolates into the mass of the deposit, and by its evaporation a layer of the dissolved material is thrown down which effectually cements the incoherent mass, converting it into a hard rock. Generally, both these agents, pressure and infiltration, work together towards the same result.

Rocks which have been formed in water are called **aqueous** rocks. They fall roughly into two groups, known respectively as *siliceous aqueous rocks* and *argillaceous aqueous rocks.*

Siliceous aqueous rocks *are derived from the insoluble quartz, resulting from the decomposition of igneous rocks* (p. 205), *and separated from the other products by the action of running water.* Names are given to different rocks formed in this way, according to the size of the constituent grains. The following are some of the chief:

Sandstones are composed of fine grains of quartz cemented together by different substances. Before this consolidation, the quartz grains constitute a **sand.** A descriptive adjective is added to direct attention to the nature of the cement, thus, *red sandstone* in which the grains of quartz are held together by a red oxide of iron; *calcareous sandstones,* in which the cement is carbonate of lime. *Freestone* and *flagstones* are sandstones which can be used for building and paving respectively. *Micaceous sandstones* contain flakes of mica along the planes of bedding.

Argillaceous aqueous rocks *are derived from the most finely divided insoluble substances resulting from the decomposition of the constituents of igneous rocks* (p. 205). This class of rock comprises the different varieties of **clay**, hence the name *argillaceous* (Lat., *argilla,* clay). Kaolin is white, but other clays are of different colours, depending chiefly upon the amount of the oxides of iron present. The chief varieties of this class of rocks are:

Mud and **Silt** are names given to the fine loose materials which settle in quiet waters. When more compact and plastic they pass into clay.

Mudstone is hardened mud with no disposition to split up into layers.

Shale is hardened mud, which can be divided into thin layers or laminæ. It is known as *carbonaceous shale* when it can be used as fuel.

Rocks formed by the aid of animals and plants.—Among the materials which water dissolves in favourable circumstances from rocks are silica and calcium carbonate (chalk). Neither of these compounds is soluble in pure water, and the first owes its solution to the presence of alkaline carbonates in the water, the latter to carbon dioxide (p. 221) derived from the air. As a result of this action sea water contains about 2½ grains of dissolved calcium carbonate per gallon, and an even smaller proportion of silica. Calcium sulphate, which is much more abundant than either, is directly soluble in water. Variable quantities of the same compounds occur in rivers and lakes.

Either calcium carbonate or silica, obtained directly or indirectly * from the surrounding water, forms the main source of the hard parts—the shells or other supporting or protective structures—of many aquatic animals and plants. When the organism dies its soft parts decay; its hard parts accumulate if the circumstances are favourable, sometimes in sufficient quantity to form extensive deposits over the bed of the sea.

Organic rocks composed of calcium carbonate.—Organic rocks formed by animals are much more abundant than those which plants build up. It will simplify the matter to consider first the work of plants in this connection:

(1) *Formed by plants.* Many minute seaweeds have the power of extracting calcium carbonate from sea water. The carbonate sometimes helps to make up parts of the plant itself, at other times it is deposited outside the organism only, forming an incrustation. Small rounded lumps of calcium carbonate, called

* There is reason to suppose that the calcium sulphate, rather than the calcium carbonate, dissolved in sea water, furnishes the lime of the hard parts of marine animals. The calcium sulphate is apparently acted upon by ammonium carbonate produced by the animal, and thereby converted into calcium carbonate.

coccoliths when single, or *coccospheres* when collected in masses, and formed in this way, occur on the floor of part of the Atlantic Ocean. They also occur in masses of chalk.

Certain rocks—called *oölitic* and *pisolitic* limestones—which play an important part in the topography of Great Britain and other countries, are composed of small, rounded grains. Such limestones were supposed, until recently, to have been formed in every case by the gradual deposition, from solution, of concentric layers of calcium carbonate around minute grains of sand or tiny

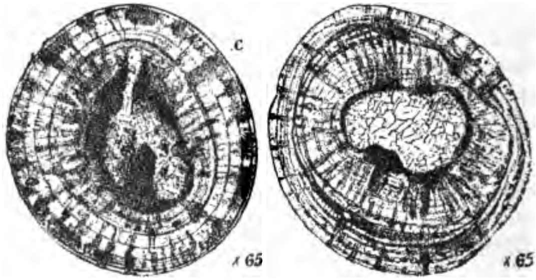


FIG. 118.—Oölitic granules from the Forest Marble near Cirencester. (Wethered, Q.J.G.S., Vol. LI., Plate 7.)

shells. The successive layers are seen very plainly in the magnified sections shown in Fig. 118. It is now believed that in some oölite grains, the layers of calcium carbonate were laid down by a minute alga or seaweed.

(2) *Formed by animals.* Many animals extract calcium carbonate* from the waters in which they live, and use it to build their hard parts. All the so-called "shell-fish" do this. Some of the most abundant rock masses have been built by the accumulation of the remains of the most insignificant animals.

Chalk is composed chiefly of the skeletons of very lowly animals belonging to the group called *Foraminifera*, the most commonly occurring member of the group being *Globigerina*.

Foraminifera flourish in abundance at the present day in the Atlantic Ocean, and the accumulation of their skeletons forms the **ooze** found on the ocean floor. The chalk which makes up

* Footnote, p. 197.

great rock masses in the south-east of England as well as in other countries contains many such foraminiferal shells, with the larger shells of many other organisms, and was once held to be of similar origin to the abysmal ooze of the Atlantic Ocean. Fig. 120, of globigerina ooze and a section of chalk side by side, shows how similar these deposits at first sight appear. Chalk is now known, however, to have been formed at a much smaller depth than the ooze, and it should be noted that foraminiferal deposits to-day are also found in only moderately deep water.

Coral.—Other marine animals higher in the scale of life than the foraminifera, which also make use of the calcium carbonate extracted from sea water * for building up their hard parts, are coral polyps. They are related to sea anemones.

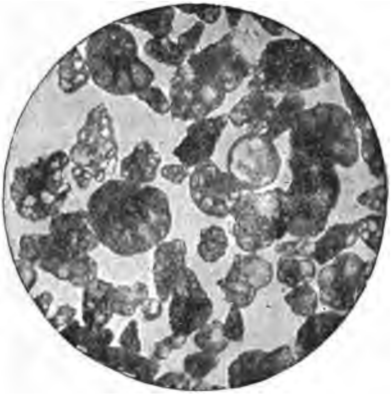


FIG. 119.—Foraminifera from Saint Helena, Nebraska.

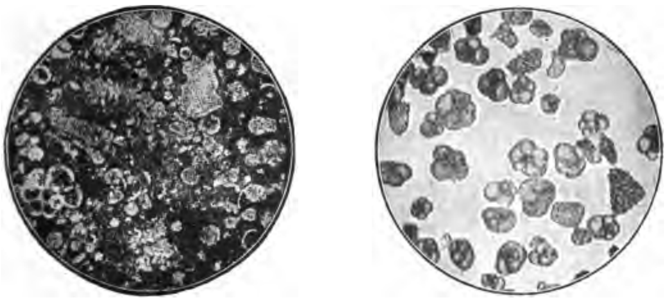


FIG. 120.—Similarity of organic remains in chalk and Atlantic ooze. (From photographs by Mr. J. E. Barnard.)

Coral polpys can flourish only in clear moving water, which is not below a temperature of 68° F., nor at a greater depth than about 120 feet below the surface. Reef-building corals are not

* Footnote, p. 197.

often found in latitudes much more than 20° from the Equator. These coral polyps live in colonies, and the result of their existence and reproduction is the formation of masses of coral like that shown in Fig. 121. Reefs made entirely of the skeletons of these coral animals are sometimes very extensive, as, for example, the Great Barrier Reef of Australia, which has a length of upwards of 1200 miles along the north-eastern coast of that continent (Fig. 121).

Photo. W. Saville-Kent.

FIG. 121.—A low, woody coral-reef, Outer Barrier, Australia.

Limestone, also, is made up of calcium carbonate forming the remains of animals. It was secreted by them to form their hard parts. There are many kinds of limestone formed by different animals. Thus, **encrinital limestone** (Fig. 122) is built up almost entirely of the jointed remains of animals called sea lilies, nearly related to star fishes and sea urchins. **Shell limestone** is composed of shells large enough to be recognised by the naked eye. Some limestones occur in which the animal remains have been broken up and reduced to a mud (earthy limestone), and others in which crystallisation by percolating water has taken place.

Organic rocks composed of silica.—*Those formed by plants.* These plants are known as **diatoms.** They are generally microscopic in size, but have existed in sufficient numbers to form, by the accumulation of their hard remains, beds of considerable thickness. Their hard framework is made of the silica which the living diatom extracted from the water, either fresh or salt, in which it lived. At Richmond, in Virginia, beds of forty feet thick occur, and these consist entirely of the remains of diatoms. *Diatomaceous earths* and *Tripoli powder* have been made in this way.

FIG. 122.—Weathered surface of Crinoidal Limestone (Carboniferous) from Derbyshire. From a specimen in the Manchester Museum. (About ½ natural size.)

Sinter is a rock resulting from the deposition, by algæ, of the silica which they have extracted from the waters of hot springs (p. 180).

Those formed by animals. Silica-secreting animals, like foramaminifera, belong for the most part to the group of simplest animal structure known; they are called **Radiolaria.** Their remains build up the *Radiolarian earths* which occur in various places. A good instance is provided by the radiolarian earth of Barbadoes. Certain sponges, called siliceous sponges, also have this power of extracting silica from the water in which they live. They utilise the silica to form the *spicules* commonly associated with the remains of radiolaria.

Organic rocks composed of the remains of land plants.—These rocks are sometimes called *Carbonaceous rocks*, and include peat, lignite, coal, anthracite and graphite.

Peat is the first stage in the formation of certain varieties of coal. It has none of the characters usually associated with rocks, and is included here because it helps to build up the crust of the earth, and to complete the stages in the formation of coal. If obtained near the surface of the ground, peat is an incoherent mass of vegetable fibres. As it is traced further below the earth's surface it becomes more compact, gradually losing its fibrous appearance. It is formed at the bottom of marshes. Water-loving plants, like

certain mosses, by their rapid growth, gradually encroach upon the water expanse round which they grow, until eventually it may be obliterated, its place being taken by a mass of vegetable matter, still growing on the top, but composed beneath of the accumulation of the dead parts of the plants of previous years. Such areas constitute **peat mosses** or **bogs**. Bogs are abundant in temperate countries, where the conditions are favourable for their formation. A section of an Irish peat bog, showing the growths of three successive submerged forests, is given in Fig. 123.

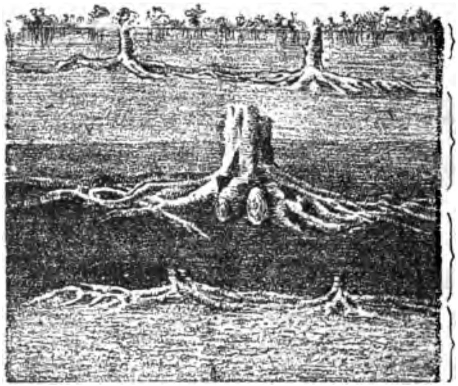


FIG. 123.—Section of an Irish peat moss. (From *Knowledge*.)

Lignite.—If the land on which a peat bog has been formed subsides to any extent, it will become covered probably with water, and there may be deposited above it a bed of sedimentary rock. This bed of rock will subject the peat to pressure, and cause it to become compacted further. The form then assumed is that of a brown rock, called brown coal, or *lignite*.

Coal.—It appears likely that coal of the Carboniferous age, which is the commonest kind in this country, was formed by a process which began with the exceedingly slow subsidence of estuaries and deltas to form great swamps, on which vegetable debris accumulated. This material was partly derived from the estuarine vegetation previously growing on the area affected, partly from plants still flourishing on the sinking land, and partly from drifted vegetation brought down by rivers from forests on

higher ground. By further subsidence the vegetable matter was covered by the sea, and buried beneath deposits of sand, chalky material, etc., being thus subjected to immense pressure and thereby converted into coal. At a later stage the same area was gradually upheaved, to be again invaded by plants. "Thus a new cycle of *upheaval—abundant vegetation—depression—carbonaceous deposits*—was initiated, and this sequence was repeated hundreds of times during the Carboniferous period." *

FIG. 124.—A bed of coal showing the trunk of a large plant of the carboniferous period. (From a photograph by Mr. A. G. Nichols.)

The vegetation of the Carboniferous period included a much larger proportion of **cryptogams**—plants which do not produce flowers or seeds—than is found at the present day. The cryptogams include ferns, horsetails, club-mosses, true mosses, and others. Relatives of most of the cryptogams which formed the coal are found living to-day, but they have now little importance compared with the *flowering plants*, which include not only plants bearing "flowers" as the word is ordinarily understood, but also all our forest trees and grasses, as well as the commonest weeds. Coal is often spoken of as being formed from ancient forests, but it should be remembered that very few trees, as we know them now, grew at the time when the plants, which formed the coal, flourished. It is, however, a fact that some flowerless plants, allied to our club-mosses and horsetails, then grew to a great size, and were as large as some of our trees. It is not common to find complete plant remains in coal

* Arber's *Natural History of Coal* (Camb. Univ. Press).

itself, but in the shales associated with it perfectly preserved leaves and other parts of plants occur.

Much work has recently been done upon "coal balls," which are more or less spherical masses in which many stems, leaves and seeds of various coal plants occur. Remains of the whole plant are replaced and cemented together by calcium carbonate. These coal balls, which always occur associated with the coal, show the replaced cell structure of the contained plant fragments so well, that the botany of these plants is now becoming well known. It

FIG. 125.—Stalactites and stalagmites from Clapham Cave, Yorkshire. (From a photograph by Mr. G. Fowler.)

has been shown that many plants, until recently considered to be ferns, formed seeds; and the old idea that all coal plants were cryptogams has been given up.

Anthracite is more highly mineralised than ordinary coal. It contains a greater percentage of carbon and a smaller amount of hydrogen in 100 parts than ordinary coal. It is called smokeless coal sometimes, because of the way in which it burns.

Graphite.—If everything but the carbon is expelled from the plant remains by the action of the pressure and heat, the final result is the variety of carbon known as graphite.

Aqueous rocks formed by chemical means.—Rocks formed by deposition of calcium carbonate from solution are **stalactites** and **stalagmites** (Fig. 125), and *calcareous tufa* or *travertine*.

Beds of *rock salt*, *gypsum* and *dolomite* are also formed by a somewhat similar process from solutions of other substances.

23. UNSTRATIFIED ROCKS.

1. Igneous rocks.—(*a*) Examine a piece of *granite*, such as is often used as "road metal." Observe the crystals of which it is composed. The clear glassy crystals consist of *quartz*, the cloudy or milky crystals of *felspar*, and the dark shining crystals of *mica*, or sometimes *hornblende*.

Smash the lump of granite and notice that there is no sign whatever that it consists of layers.

(*b*) If possible also examine other igneous rocks. Classify them as obviously crystalline, or doubtfully crystalline to the naked eye, and obviously glassy. Has any of these rocks any resemblance to slag?

2. Metamorphic rocks.—(*a*) Examine a piece of *roofing-slate*. Test it with careful blows with a hammer in different directions.

Try the effect of a drop of acid on it.

(*b*) Similarly examine and test a piece of *marble*.

(*c*) If possible, examine a hand specimen of the rock *quartzite*. Study the surface of fracture with the help of a lens. Can you see any evidence that the rock has been strongly heated?

(*d*) To which of the stratified rocks, limestone, shale and sandstone, do you think the three metamorphic rocks examined have respectively the most resemblance? Give reasons for your conclusions.

Igneous rocks.—These rocks include all which have at some time in their history been in a molten condition. Their physical character depends almost entirely upon the *rate* at which they have cooled. In those cases where the cooling has been comparatively rapid, as, for instance, with the lavas poured out from volcanoes, what are called **volcanic** rocks are obtained; in these crystallisation is by no means perfect, with the result that they consist largely of a glassy material.

Examples of such **volcanic** rocks are: (*a*) *basalt* (Fig. 102); (*b*) *obsidian*, which is not distinguishable in appearance from some kinds of bottle glass; (*c*) *andesite*, which takes its name from the Andes mountains, where varieties of it occur in great quantities. Andesites are perhaps the most abundantly found of all the igneous rocks.

In those rocks, however, where cooling has been very slow, as

is the case with those which have cooled deep down in the earth's crust, under the great pressure caused by the weight of the overlying layers of the earth's crust, crystallisation is very perfect, and there is no glassy material present. Such rocks are called **plutonic.** **Granite** is the typical plutonic rock. It is a valuable building stone.

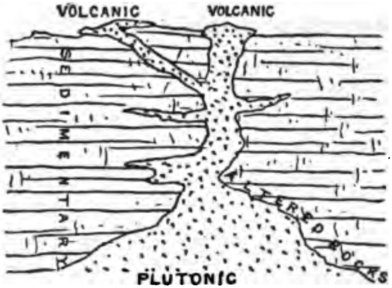


FIG. 126.—Volcanic rocks are lavas cooled near the earth's surface. Plutonic rocks are lavas cooled deep in the earth's crust.

There is no sharply defined line of demarcation between volcanic and plutonic igneous rocks; they merge the one into the other, and the intermediate types are sometimes distinguished by the name of **dyke** rocks.

Metamorphic rocks.—All rocks classed under this heading are *changed* or *altered* rocks. The changes have been brought about by a variety of causes, such, for example, as the heat of contact of an intruded mass of molten rock; or by the pressure accompanying the great movements which have from time to time taken place in the earth's crust (p. 215). There is a great diversity in character among the rocks of this class.

Igneous, sedimentary and metamorphic rocks are dependent upon one another. Their interdependence becomes apparent when it is remembered that in many cases the materials necessary for the formation of the sedimentary rocks are obtained from igneous rocks, and that these stratified rocks may, under the influence of the changes mentioned, give rise to rocks styled metamorphic, which in some cases can only be distinguished from igneous rocks with difficulty.

Those changes which cause a sedimentary rock to lose its original texture completely and to become crystalline, are classed as *metamorphic changes*, and are said to be due to **metamorphism.** Such metamorphism is the result, as a rule, of two important causes. First, that due to the heat of contact with great masses of intruded molten rock—which is, by the expansive force of

steam, or some other cause, forced from below into crevices and fissures, or between the beds of the overlying stratified rocks.

Secondly, the change may be brought about by the action of enormous pressures from the sides. This is generally the outcome of slow movements of the earth's crust.

Where metamorphism has been fairly complete, *sandstones* are changed into **quartzites**. Though hand specimens and sections under the microscope both reveal the origin of quartzite from quartz grains, yet these minute fragments are cemented together firmly, and the rock cannot be pounded up like a sandstone. It breaks with difficulty, and the fractured surface shows the interlocked grains broken across.

By metamorphism *chalk* is changed into either **marble** or *crystalline limestones*. Though typical marble is white, it may, as the result of impurities of one kind or another, be of almost any colour.

The effect of metamorphism upon *clays* and *shales* is to change them from a rock easily divisible into laminæ along the planes of bedding, into one known as a **slate**, exhibiting the phenomenon of *cleavage*. The rock no longer splits along the original planes, but along a new set which are usually vertical or inclined at angles approaching a right angle.

24. THE SLOW MOVEMENTS OF THE EARTH'S CRUST.

1. The result of lateral pressure on strata.—Arrange differently coloured rectangular pieces of cloth in a heap, and place a piece of board of the same height as the pile at each end of the heap. Place a third piece of board, or a book of a suitable size, along the top of the pile with a weight on it. Now apply a lateral pressure, by pushing with both hands simultaneously against the end pieces of board, and notice the folding of the layers of cloth.

FIG. 127.—To illustrate the terms outcrop, dip, and strike, applied to strata.

2. Outcrop, strike, dip and escarpment.—Make a tidy pile of a heap of books lying on their sides; they represent horizontal strata. Now push them over so that they lie as in Fig. 127; they now simulate inclined strata, and the upper surface of the pile is made up of the succession of the front

edges of the books. Such an edge of each book at the surface represents an *outcrop*; the direction in which the edge of a book points is its *strike*; the angle the covers of the books make with the horizontal is the *dip*. Arrange the books so that the dip is small (*e.g.* 10°), and let them overlap; then the upper cover of each book represents the *dip slope*, and the upper edge of the book represents the *scarp slope*, of an *escarpment*.

Slow movements of elevation and depression.—The earth is quoted popularly as an almost perfect example of stability, while the ocean is looked upon as ever changing its level. We have now to see that in reality the reverse of this is true. The expression *terra firma* is founded on a misconception, for the land level is changing continually, being raised in some districts and depressed in others. The sea level on the other hand is, in a general sense, constant, so that it is properly used as a base from which heights and depths may be reckoned.

Since the movements of the land just referred to are very slow, and extend over great periods of time, they are called **secular movements.** They result eventually in a complete alteration in the contours of land and water. New stretches of land are formed by the gradual upheaval of the floor of the sea, while in other parts, owing to depression of the land, the sea encroaches and submerges tracts of country bordering the ocean.

Proofs that the level of the land is being raised in some parts of the earth are of several kinds:

(1) *The beds of sea shells, similar to those of animals still living in the sea, found near the coasts of various countries, but raised to different heights above the sea level.* Along the coast of South America such shells are found at a height of 1,300 feet; in Norway up to 700 feet; and along the shores of Sweden at elevations varying from 100 to 200 feet.

(2) *The raised beaches which occur round the coasts of Britain and other countries.* These old sea terraces were evidently at one time at the margin of the sea. This fact is placed beyond a doubt by the water-worn rocks constituting the old sea-caves which often form the background of such beaches. Raised beaches of this kind occur at various places round the Scottish coast (Fig. 128) and in one or two places round England. In Fife, three beaches, at 25, 50, and 100 feet above sea-level, can be traced for considerable distances. Good examples are also to be

found in the north of Norway, where a whole series occurs up to a height of more than 600 feet.

(3) *The present elevated position of certain human erections which were originally at the sea level.* A good example is afforded by the old Greek docks, which are now found much above the sea level on the southern coast of Crete.

FIG. 128.—Old sea caves cut in the sandstone cliff at the edge of a raised beach, Drumadvon, S.W. Arran. (Photographed by the Geol. Survey of Scotland.)

Proofs that the level of the land in some parts is sinking:

(1) *The present position, below the water, of certain human erections which were built originally above the sea level.* This is true of several old streets of some seaports on the south coast of Sweden. The poles which the fishermen of Greenland in past times have put into the beach as an attachment for their boats now lie useless below several feet of water. Similarly, new posts are being put in continually to take the place of those which become submerged as the land sinks.

(2) *The submerged forests which are not uncommon round the coasts of Devon, Cornwall and other places.* From the nature of the trees which make up these forests we are quite sure that they must have once lived on the land. Their present position gives an unmistakable proof that the land is sinking in these parts, or, at all events, has sunk in past times.

(3) *The existence of coral at a depth of as much as* 1,800 *feet in certain coral reefs, though it is well-known that the coral polyp, which builds the coral, cannot live below a depth of about* 120 *feet.* It was suggested by Charles Darwin that coral reefs afford proof

FIG. 129.—Nukapu Island, a coral island in the S. Pacific.

of the subsidence of the land in the districts where they occur. On this theory the coral polyp must have commenced its work at a depth of about 120 feet, and have built upwards at something like the rate at which the land was sinking. At first the coral would form a ring round the island, such as is seen in section in

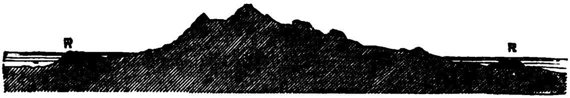


FIG. 130.—Section of a fringing coral reef.

Fig. 130. This stage is known as that of a **fringing coral** Now imagine the island, *L*, to sink gradually as a whole. This would carry the fringing reef with it. But the coral polyps continue to build all the time and raise the reef to the same extent as the land subsides. They also build more quickly on the outside, where the supply of food is best maintained, and as a result the fringing reef gradually assumes the **Barrier Reef** stage

(Fig. 131), where a small island is surrounded by a circular coral reef.

The continuance of the same process eventually carries the island, *L*, completely beneath the water, and all that is seen at the surface is a circular island of coral, known as an **atoll**, as in Fig. 132.

FIG. 131.—Section of a barrier reef.

Continental elevation.—Large tracts of country are found to show sedimentary rocks beneath the soil. In the strata we find deep sea, shallow marine, estuarine and fresh-water deposits, giving evidences of many changes of level. On definite horizons, beds with characteristic fossils occur, and indeed the whole sequence of beds has been divided into systems (Fig. 117) which can be traced from one country to another. There are often unconformities in the bedding and interruptions in the life records (fossils), and the whole forms a most fascinating story of upheaval

FIG. 132.—Section of an atoll.

depression and deposition in repeated cycles. If our knowledge were more complete it would be possible to obtain clear ideas of the geography of the world in all the different periods. Our present geography, known so much more definitely by us, is but that of the last of these periods.

Let us, however, select one case from a multitude of instances. The south-east of England is built up largely of a great stretch of **chalk**, which extends right across the continent of Europe. In few places is there any great departure from horizontality, showing that the rock has been subjected to no violent movements. Yet from the nature of the chalk (pp. 198 and 199) and the manner in which it is known to have been deposited, it is certain

that when the chalk was being formed a large part of Europe must have reposed beneath moderately deep water, and that, by the force of a gradual though irresistible upheaval, it has been raised subsequently above the sea level and there subjected to the sculpturing power of atmospheric denudation (p. 221). From the consideration of such cases as this we are led to the conclusion that

FIG. 133.—Horizontal strata, "Marble Cliffs," Porthmissen, Padstow. (Photographed by the Geol. Survey of England and Wales.)

continental elevation may be brought about without any extensive fracturing or crumpling of the rocks.

Other positions of stratified rocks.—Though geological formations may retain their original horizontal arrangement (Fig. 133), they have been subjected more commonly to some degree of movement resulting in what are known as inclined and vertical strata. When the originally horizontal strata have, in consequence of movements in the earth's crust, been pushed up so as to become inclined at an angle to the horizon, they are called **inclined** strata (Fig. 134). When this angle is a right angle the

strata are spoken of as **vertical.** In some cases the order of the beds has been reversed completely, the older and first deposited stratum coming to lie over the younger later beds; in such a condition of things we have **inverted** strata.

The angle which inclined strata make with the horizon is called the **dip** of the beds. In the case of horizontal formations the dip

FIG. 134.—Highly tilted limestones, Liddel Water, Dumfries. (Photographed by the Geol. Survey of Scotland.)

is, of course, nothing; while that of vertical beds is 90 degrees. In some cases strata lie horizontally, or nearly so, upon the upturned edges of other strata, as in Fig. 135. The stratifications thus do not agree with one another, and are therefore said to be **unconformable.**

Outcrop.—The extent to which a bed is seen at the surface depends upon the size of the angle of the dip and the thickness

of the bed, as well as upon the surface contour of the country. When a series of strata is horizontal, it is apparent that only the uppermost bed can appear at the surface, until, at all events, some part of the bed immediately beneath becomes exposed by the washing away of parts of the surface stratum. When beds have become inclined, however, each bed in succession is found at the surface, and the smaller the angle of dip the wider, in general, will be the part of the bed exposed. This exposed portion the geologist calls its **outcrop**. The width of the outcrop, then, is least for vertical beds, and in this case only is it an exact measure of the thickness of the stratum. The point of the compass to which the outcrop on a horizontal surface points is called the **strike** of the stratum in question.

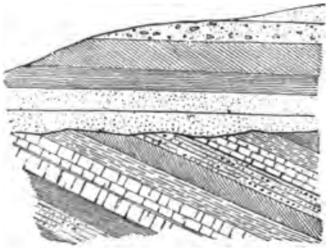


FIG. 135.—Uncomformable strata. From *An Introduction to Geology*, by Prof. W. B. Scott. (Macmillan.)

In observations of the dip of the individual members of a succession of beds it often becomes very noticeable that there is a gradual diminution in the size of the angle, indicating that, in reality, the exposed parts of the bed are parts of large curves, or folds, into which the strata have been thrown by great movements in the earth's crust. Such folds must next be considered.

FIG. 136.—Perspective view and vertical section of Anticlinal beds. (From a *Report of the U.S. Geological Survey.*)

Folding of strata.—When horizontal strata are subjected to enormous lateral pressures, as a result of the great movements of the earth's crust, they become thrown into folds in a manner which can be easily imitated by Expt. **24**, 1.

Where strata dip away *from* the same line, as the pieces of cloth do in the crests of the wave-like folds into which the layers of cloth were thrown in Expt. **24**, 1, what is known as an *anticlinal fold* or **anticline** is formed, the line along the arch from which the

strata dip being referred to as the **anticlinal axis** (Fig. 136). When, on the other hand, strata dip *to* the same line, as in the troughs of the experiment, what is called a **syncline** is formed, the corresponding line in this case being called the **synclinal axis** (Fig. 137).

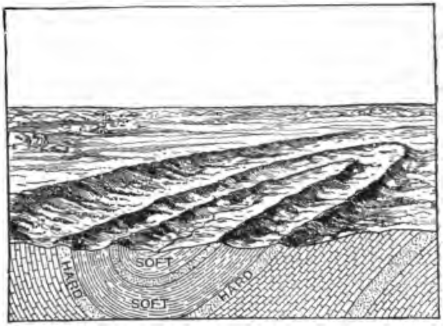


FIG. 137.—Perspective view and vertical Section of Synclinal beds. (From a *Report of U.S. Geological Survey*.)

Such folding is common in different places, especially in mountain ranges, which probably owe their origin, in a great degree, to lateral pressures, similar in kind though enormously greater in degree, to the force exerted by the hands in Expt. 24, 1 (Fig. 138). Folding is only one of the results of forces such as these. They also bring about the metamorphic changes dealt with on pp. 206 and 207.

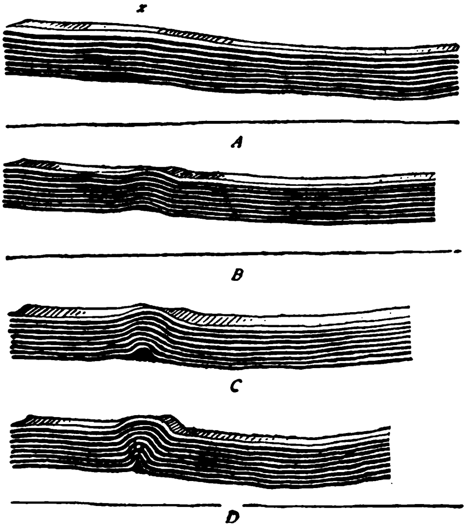


FIG. 138.—Diagrams showing stages in the formation of a folded mountain chain by lateral compression. (Adapted from *An Introduction to Geology*, by Prof. W. B. Scott.)

Generally, denudation (p. 221) has obliterated effectually all evidence of folding which may at one time have been apparent at the surface. The continued wasting brought about by atmospheric agencies and the washing away of material effected by running water, not only remove the tops of the anticlines, but also pare down the whole of the folded crust to a more or less dead level. But where any section is laid bare, as in sea cliffs, railway cuttings, or many other

such exposed places, any folding which has occurred becomes apparent.

The movements which have from time to time taken place in the earth's crust, sometimes actually fracture the strata under the enormous pressure. Such fractures or breaks in strata are classed together as **faults** (p. 182). The work of denudation is not relaxed all the time the process of slow faulting is going on, and consequently there will probably be no great step occurring at the surface of the crust. Indeed, faults are only to be recognised usually by a careful survey of the beds of the district along which they run.

Production of mountain structures.—Mountains are neither all of the same kind nor formed in the same manner. A few of the commonest causes only can be considered here. In some cases **volcanic action** has been instrumental in building up cones of one form or another all along a line of weakness, as in the case of the range of the Andes, which essentially consists of a chain of volcanic mountains. In other cases, mountains consist of the remains of hard rocks, either igneous or sedimentary, which have resisted **denudation** to a greater extent than neighbouring strata, and are therefore left projecting above the general level of the district. The most important mountain ranges, however, have been produced by the **folding** and upheaval set up by slowly acting but enormous pressures in the earth's crust. Such pressures are no doubt caused in various ways, but it is easy to understand that the continual transference of immense weights of material from high lands to low plains, which is brought about by rivers, is in itself sufficient to cause immensely powerful lateral or side pressures, which throw the crust into huge folds (Fig. 139) along lines of weakness, also producing faulting and metamorphic changes. Finally, the persistent influence of the weathering and denuding actions of atmospheric forces causes the upheaved ridge to become sculptured into the characteristic and picturesque forms which we associate with mountain ranges.

As has been explained, the enormous lateral pressures to which the earth's crust has been subjected at various times produce anticlines and synclines. A mountain range, however, rarely consists of an unchanged anticline, but more commonly the whole has been greatly denuded, and the hardened (because more highly compressed) anticline or syncline remains as a mountain range. In Britain, for instance, the Pennine Chain is the remains of an anticline. The older strata occur at the centre of the range, and the newer dip on each side away from the centre. The Lake district, too, shows a dome-like arrangement of its strata (p. 234), and the newer beds occur in shells outside the older core of

volcanic rocks and slates. An even better example is afforded by the Weald (Fig. 148).

At the top of Snowdon a distinct syncline is to be seen. The beds of which it is formed are of volcanic ashes, and the trough at the top remains as evidence of the vast amount of denudation which has taken place.

The Alps are an example of a complicated range of mountains. The numerous ranges which occur show an abundance of contorted and crumpled rocks (Fig. 139).

FIG. 139.—Symmetrical folding of the rocks of Swiss Jura.

The age of mountains.—Considerable information respecting the geological age of any particular folded mountain chain is afforded by the obvious fact that the uplift must have taken place later than the time of deposition of the youngest strata involved in the upheaval. In this manner it has been found that the loftiest mountain chains now existing—the Alps, Pyrenees, Atlas, Caucasus, Himalayas and Rocky Mountains—were all uplifted in **Tertiary** times (p. 194). Indeed it is probable that some of them are still growing. On the other hand, the uplands of Ireland, the west of Great Britain, Scandinavia, Brittany, the Ardennes, the Appalachians, etc., are of much more ancient date, and must once have been lofty mountains, though they are now greatly worn down by denudation.

Earth movements in Britain.—Several movements have been recognised in Britain which must have occurred at different periods, and they are usually associated with volcanic activity and probably with earthquake phenomena. Among these may be mentioned the **Archaean movement**, one of the oldest, with ridges, faults, thrusts, and intrusive dykes running from north-west to south-east, as in the north-west Highlands of Scotland and Charnwood Forest in Leicestershire.

The **Caledonian movement**, pre-Devonian (Fig. 117) in date, follows, with many faults, the line of the Caledonian Canal. Its lines are followed by the mountains of the Scottish Highlands. The line of the Highland fault in Scotland—from Stonehaven south-west to the Clyde and Bute—is an old line of disturbance, and early in geological history earthquakes and faults must have occurred along it. At the present day earth-tremors of small magnitude, and vibrations only detected by sensitive seismographs, are common in Britain along this line and elsewhere.

The **Pennine movement**, in post-Carboniferous times, formed the Pennines and also some minor hills at right angles to the range. As a later result of this movement we have the Wealden anticline (p. 233) following the Pembroke-Mendip axis.

All these movements have produced ridges; and it must be remembered that all the hills and dales in Britain are the results of either earth movements or differential denudation. The effects of these processes in moulding the topography of our own country will be considered in more detail in Chapter X.

Volcanic activity in Britain.—During several periods in the geological record great volcanoes were in activity in Britain, and the much denuded cores of these volcanoes, ancient and altered lava flows, volcanic intrusions, large masses of igneous rocks, and so on, are left standing as indisputable evidence. These remains, long since converted into hard rocks, make very conspicuous features in the topography of the country (Fig. 144). At present Britain is not troubled by volcanic activity, and is very seldom the scene of an earthquake that has any disastrous effects; although slight vibrations in the earth's crust, the result of earthquakes more or less near, are very commonly reported.

EXERCISES ON CHAPTER IX.

1. What is shingle? Where is it generally found, and how is it formed? (C.J.)

2. What evidence is there that certain coasts are rising and others sinking? (C.S.)

3. Describe a sea beach where new land is being laid down by the sea.

4. Write a brief description of the three recognised types of coral reef and their origin. (C.J.)

5. Describe and account for two examples of destructive and two of constructive work by the sea on the coasts of England. (J.B.M.)

6. By what processes are materials, deposited on the sea bottom, converted into hard rock?

7. Give four examples of common stratified rocks, and explain the conditions under which each was formed.

8. What are the chief varieties of limestone? How was each formed?

9. In what parts of the world do coral islands occur? Describe the principal stages in the formation of such an island.

10. Give an account of the probable manner of formation of ordinary coal.

11. Explain the terms "carboniferous period," "carboniferous system." Give some account of the carboniferous rocks of Britain.

12. Distinguish between metamorphic and igneous rocks. Mention three examples of each, and explain, as far as you can, how they were formed.

13. Explain, with sketches, the meaning of the terms *outcrop*, *strike*, *dip*, and *unconformity*, as applied to strata.

14. Distinguish between the *dip-slope* and the *scarp-slope* of an escarpment. Explain your answer by a sketch.

15. Define *anticline* and *syncline*. How have these geological features been produced?

16. Write a short essay on the formation of mountain chains.

17. Mention three ancient and three recently formed mountain chains. What facts show that they are of different ages?

18. Mention evidence that active volcanoes once existed in Britain.

CHAPTER X.

DENUDATION: THE ROCK STRUCTURE AND TOPOGRAPHY OF THE BRITISH ISLES.

25. THE RELATIVE DURABILITY OF ROCKS.

1. The action of water on different rocks.—Obtain small pieces, approximately equal in size, of the following rocks : clay, shale, various sandstones, limestone, slate and granite. Put each in turn in a dish under a dripping tap for several hours and observe any differences in the rates at which the rocks are acted on by the water. If possible weigh each piece of rock before the experiment, and afterwards dry each piece in an oven (rejecting any loose particles which have become detached) and weigh again. Make a list of the rocks in order of their durability, so far as this is shown by the experiment.

2. Expansion of water on freezing.—Obtain a small, corked bottle with a narrow neck. Fill it with water and cork tightly, driving the

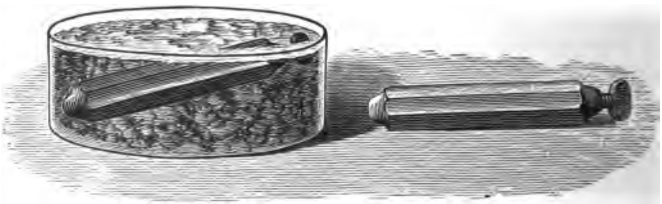


FIG. 140.—Experiment to illustrate expansion of water on freezing.

cork in as far as possible. Pass strong fine twine several times round the bottle from top to bottom and over the cork, to keep the latter in. If the string is likely to slip, notches in the cork will prevent it. A small piece of wood similarly notched and put at the bottom of the bottle will prevent the string from slipping there. A "screw-top" mineral-water bottle, filled with water and sealed by screwing in the

stopper tightly, may be used instead. Place the bottle in a bowl and cover it with a freezing mixture of ice and salt. Carefully cover the bowl with a duster or cloth until you hear the bottle burst, then take off the covering and examine what has happened. Describe and explain the result of your experiment.

If possible, repeat the experiment with a small cast-iron cylinder (Fig. 140), provided with a stopper which screws in. A louder explosion is heard.

You will understand from these experiments why water pipes burst in winter. Why is it that the pipes are not found to be burst until the thaw sets in?

3. The conditions of solubility of calcium carbonate.—(*a*) Put a pinch of precipitated chalk (finely divided calcium carbonate) into a test tube one-quarter full of water, and breathe through a tube dipping in the water so that your breath bubbles through the water. What becomes of the chalk? When the water is clear, heat it until it boils, so as to expel any gases dissolved in it. Describe any change in its appearance.

FIG. 141.—Experiment to show that tap water contains dissolved carbon dioxide.

(*b*) Clear lime water turns milky when exposed to the action of carbon dioxide gas. Breathe through a little clear lime water, by means of a tube, for several minutes, and describe the result. What gas does the experiment show to be present in your breath? How does this explain the behaviour of the chalk in Expt. (*a*)?

(*c*) To find out whether rain or river water (tap water is either rain or river water) contains carbon dioxide in solution, completely fill a gallon can or a large flask with the water, and attach a cork and a delivery tube, which has also been filled with water, dipping the end of the tube into a little clear lime water (Fig. 141). Heat the can. Gas is given off, and as it bubbles through the lime water the liquid is gradually turned milky.

Denudation.—The result of the various activities of water in its different forms, and of air and changing temperature, upon rocks is continually to wear away exposed surfaces and thus to denude or *lay bare* parts of rocks which were previously protected from their attacks. For this reason such agents are generally called *agents of denudation.*

The sculpturing of rocks by the weather.—In Chapter VII. rivers and glaciers were considered as agents by means of which the fragments, derived from the breaking down of rocks, are carried to the sea and there laid down in regular strata. The varying nature of these aqueous deposits, and the processes by which they are changed into compacted rocks and in due course raised above sea level again, to be exposed once more to degradation, were described subsequently. The effect can now be appreciated of the long-continued action of the weather upon rocks of varying composition and physical structure, and the influence this must have in moulding the configuration of the land.

The agents of rock-destruction included under the comprehensive term "weather," include water, air and the alternation of heat and cold.

Action of water.—**Rain** has a twofold action upon the rocks at the surface of the earth; it dissolves some of the constituents and also washes away the lighter insoluble ingredients. Obviously its action is more pronounced upon more soluble than upon less soluble rocks, and upon those of friable structure than upon those which have been hardened by great pressure or heat. The action which rain has in dissolving rocks is increased considerably by the presence in it of gases which it dissolves in its passage through the air. The two gases which are most powerful in this respect are oxygen and carbon dioxide. The dissolved oxygen is particularly active in bringing about chemical changes, known as *oxidation*, which indirectly causing the decomposition of rocks, facilitate the process of solution. The carbon dioxide converts certain insoluble carbonates into soluble compounds, in this way causing, amongst other similar results, the solution of calcium carbonate. The amount of calcium carbonate which thus becomes dissolved is in some limestone districts very great. The consequence is that large **caverns** are carved out of the limestone, which is itself composed of calcium carbonate.

The formation of **soils**, and of the layers of decomposed rock occurring immediately beneath these superficial layers, known as **sub-soils**, is partly traceable to the action of rain. Other active influences concerned in their formation are vegetation and certain lowly land animals, chief among which is the earthworm.

An interesting example of the total extent of the rain's activity in earth sculpture is seen in **earth pillars**, like those of Tyrol and elsewhere. The surface rock in the district where these pillars abound is either a soft clay or shale which is easily worn away. Sprinkled over the surface, however, are lumps of hard rock on which the rain has little or no action. These serve to protect the soft material underneath them, and the result of the continued action of the rain is to produce pillars of the soft clays, each protected by its own covering of hard rock.

The so-called **grey wethers**, common in Wiltshire, which get their name from their likeness at a distance to a flock of sheep, consist of blocks of sandstone and similar rocks. They are sometimes of a considerable size, as in the blocks composing the Stonehenge Druidical remains. They represent fragmentary remains of a stratum which extended all over the area where they are now abundant, the greater part of it having been removed by the solution and washing away effected by the rain.

Action of frost in breaking up rocks.—When water turns into ice it expands. And when freezing occurs in the crevices or pores of a rock, the expansion forces the confining surfaces apart as effectually as if a wedge had been driven into each crevice. Every additional crack thus opened affords lodgment for more water after the next thaw, so that each frost has an increasingly destructive effect upon the rock in question. The most porous rocks are naturally broken up most quickly, but all rocks in which water can lodge at all are similarly affected in some degree by exposure to alternate freezing and thawing, whether they are masses of large size or the looser clods of earth which we call soil.

In this connection may be mentioned also the effect of unequal expansion and contraction, caused by the difference in the temperature of night and day, and of summer and winter, in producing fractures in rocks. (A familiar example of the same phenomenon is seen when hot water is poured into a tumbler of inferior quality.) Here, again, it is obvious that rock structure will determine very largely the extent of the action.

The work of **rivers** and **glaciers** in modifying the surface features of a country is of paramount importance, and has been considered already.

Sculpturing of the land by the ocean. This sculpturing occurs almost entirely along the coast line of the continents. The ocean currents and movements of the sea other than those on the beach have little, if any, effect in wearing away the land. The work of the *Challenger* Expedition has shown that the floor of the deep parts of the ocean is covered with a fine muddy deposit, which it is evident would not remain undisturbed were there any perceptible movements of the ocean waters. In those parts of the ocean sufficiently near to the land for sand or other material to be held in suspension, any movement of the water will bring about a certain amount of wearing away of the sea floor, but nothing of importance.

The bulk of the destructive work accomplished by the sea is above low-water mark. Its extent is generally magnified; the estimates which have been formed of its amount have been exaggerated as a result of dwelling too much upon the activity of the ocean during storms.

The work which is accomplished by the sea is of several kinds. Foremost is the work of erosion effected by the waves, which, dashing against the cliffs, hurl any loose material within their reach with a violence which is ordinarily great, and during storms stupendous. The noise of shingle being moved in this manner can be heard at a distance of several miles. Not only are the cliffs broken and worn into stacks, buttresses and needles (Fig. 142), but the stones themselves are ground and worn until they assume the size and smoothness with which all visitors to the western watering-places of Great Britain are familiar. But the breakers alone are often of sufficient force to wrench off huge masses without any aid from loose detritus. Many examples are on record, but it will be sufficient to instance the case of the moving of a block weighing fifty tons by the waves at Barrahead in the Hebrides.

The alternate compression and expansion of air in the crevices of rocks exposed to heavy breakers often dislocate masses of stone far removed above the direct reach of the waves. The hydrostatic pressure of those portions of large waves which enter passages in the cliffs also acts in forcing off huge masses from the rocks.

The air as an agent of erosion has been referred to already in connection with the oxidation and solution of rocks. Besides this chemical action, the air, when in motion as **wind**, exerts a mechanical force which has far-reaching effects. Loose particles of soil and other materials are constantly blown into rivers; the sand of the sea shore is driven hither and thither by the wind, forming, in many places, extensive "**aeolian**" **deposits**, called **sand dunes** and—what is more to the point for our immediate purpose—

FIG. 142.—Coast scene showing marine denudation, Shrinkle Haven, Manorbier, Pembroke. (Photographed by the Geol. Survey of England and Wales.)

bombarding, wearing down and polishing neighbouring rocks with a force which can be guessed dimly by those who have experienced its effects upon the cheeks.

A **sand dune** owes its origin to some inequality or obstacle on the surface over which the sand is being blown. A ridge or dune of sand is thus formed, which ultimately may attain a considerable size. The dune is steeper on the windward side and more gently sloping on the leeward side. Sand is driven little by little up the steeper slope by the wind, and falls down the other side. In this manner dunes composed of loose sand travel slowly in the direction of the prevailing wind. Over dry plains and on sea coasts

the migration of sand dunes has sometimes very destructive effects, and in many places along the west coast of Europe systematic planting of shrubs and grasses, in order to bind the sand together, has long been practised.

FIG. 143.—The white sands, Tularosa Desert, New Mexico. Parallel dunes with characteristic vegetation can be seen.

The purpose of this section has been to emphasise the fact that the rate and extent of denudation vary according to the composition and hardness of the rocks upon which the agents of denudation act. The effect which such varying action in the past has had upon the present topography of our own and, incidentally, upon that of some other countries will next be considered.

26. BRITISH TOPOGRAPHY AS A RESULT OF DENUDATION.

1. Mountainous regions of England and Wales.—Examine an orographical map of England and Wales (Fig. 75), and note the position of all *land above 600 feet.* Observe that it is nearly all to the north and west of a line reaching from the mouth of the Tees to the mouth of the Exe. Cover the map with tracing paper, and on it draw the 600 feet contour line. Now examine Fig. 144, or other geological map.* Find on it the outcrops of (*a*) igneous and

* An excellent coloured geological map of the British Isles, published by the Geological Survey (1906) on a scale of 25 miles to the inch, may be obtained for 1s. 6d.

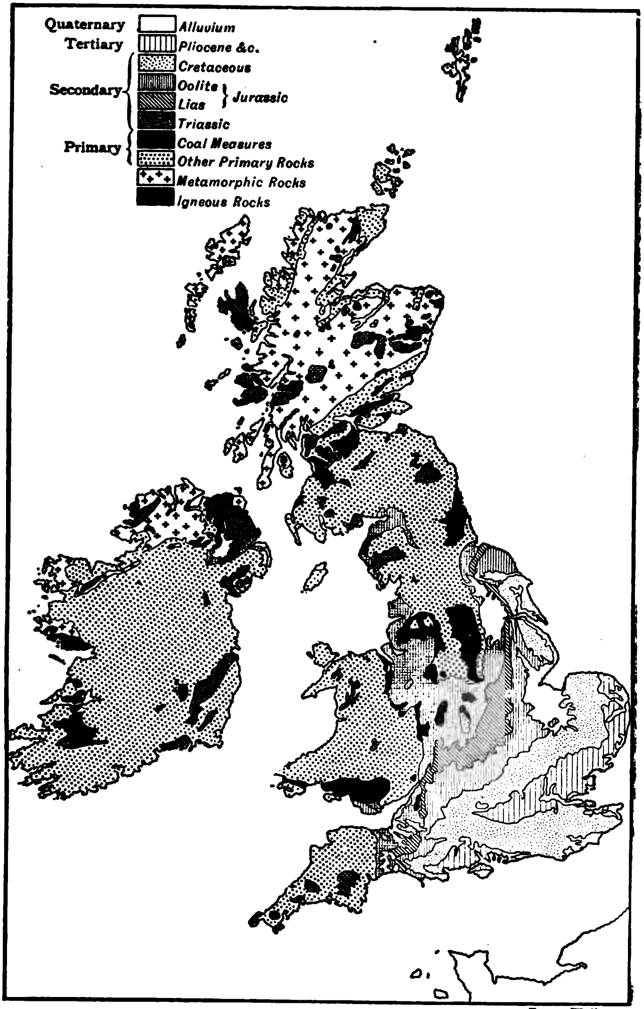


FIG. 144.—Simplified Geological Map of the British Isles.

metamorphic rocks, (*b*) the various Primary (Palaeozoic) strata, particularly (*c*) the Carboniferous system, including the Coal Measures.

Certain sandstones, slates. and limestones of (*b*) have been compressed enormously, and are therefore very hard. How does this account for the mountainous character of the regions in which they occur? Notice carefully the positions of the Coal Measures.

2. The lowlands of England.—The formations known as Trias and Lias consist largely of soft or friable strata. Find their outcrops on a geological map, and then study the districts on an orographical map. What is their range of height above sea level? Is the height greater or less than that of the adjoining districts belonging to other formations? Are the rivers draining the Trias and Lias distinguished for their large or for their small size? How do you account for this?

3. The great English escarpments and vales.—Observe on the geological map the general parallelism of the Lias, Oolite and Cretaceous outcrops; further (on a detailed map), the manner in which the upper Cretaceous (chalk) gives place to the "Tertiary" beds in Hampshire and along the north, west and south of the Thames estuary, and that the chalk is absent in the Weald district. Of these formations the Oolite rocks are hard along the western edge of their outcrop, softer towards the east, and hard again in the south-west; the chalk also is hard, and the Tertiary and Wealden (lower Cretaceous) rocks relatively soft. Now compare the geological with the orographical map, and try to explain the existence of lines of high ground (escarpments—p. 208) passing through (*a*) the North Yorkshire Moors, the Lincoln Heights, the Edge Hills and the Cotteswolds; (*b*) the Yorkshire Wolds, the Lincolnshire Wolds, the East Anglian Heights, the Chiltern Hills and the Marlborough Downs; (*c*) the high chalk ridge running round the Weald; (*d*) the vales between (*a*) and (*b*), and between the North and South Downs.

4. The topography of Scotland.—Observe (Fig. 75) the broad division of the country into the Southern Uplands (chiefly composed of relatively hard Silurian rocks), the Central Lowlands (chiefly composed of relatively soft Old Red Sandstone and Coal Measures) and the Highlands (chiefly composed of hard metamorphic rocks). In each division observe scattered areas of igneous rocks. Make out from the orographical map the obvious relation between hardness of rocks and altitude of the land.

5. The topography of Ireland.—Observe that the hills of the north and south are scattered, and do not consist of continuous high ground like the Scottish Highlands and Southern Uplands. Try to account for this by information obtained from the geological map. Notice the great extent of the hard Carboniferous formation, and the

relative absence of softer rocks, in the central plain of Ireland. Why does it form a plain in Ireland and the Pennine Chain in England?

6. English river systems in relation to topography.—(*a*) In the manner explained in Ex. **15**, 5, draw the watersheds on a map of England. (*b*) Refer to an orographical map and make a list of (i) rivers which in part of their course run in a direction away from the sea; (ii) rivers which run parallel to any of the escarpments mentioned in Ex. 3 above; (iii) rivers which cut through escarpments; (iv) rivers which in any other respects take a course not understood easily.

The varied topography of the British Isles.—The surface features of our islands are so diversified in character that they afford interesting examples of almost all types of land relief. Mountains, plateaux, escarpments, valleys, plains, estuaries all occur within so small a radius that most British students can examine them personally, and can study on the spot evidences of the stages by which they have assumed their present form.

The mountains of England.—Almost all the mountains of our country occur to the north and west of a line running between the mouth of the Tees and the mouth of the Exe. Indeed, the subsidence of these islands to the extent of some 600 feet (Fig. 75) would leave of the rest of England only a few low islands where are now the highest parts of the Cleveland Moors and Yorkshire Wolds, the Cotteswold Hills, the Marlborough Downs, the Chiltern Hills and the North Downs. Most of Wales would, however, still remain above sea level, though much cut up by winding inlets. To the south and south-west of Wales a few scattered islands would remain from the Mendip and Blackdown Hills, Exmoor and Dartmoor. What is now the valley of the South Tyne would form a narrow strait between the southern uplands of Scotland and the Pennines; while the latter range, though not largely diminished in area, would be cut into two islands by a strait flowing over the present valleys of the Ribble and the Aire. Of the northern island the Lake District would form a rugged peninsula to the west.

This distribution of high and low land is not difficult to understand when we learn that the hardest rocks are also to be found on the western side of the same line. Here, as is shown on Fig. 144, are the outcrops of igneous and metamorphic rocks, as well as of the most ancient (Primary) stratified formations—

mentioned in the table on p. 195—which have become greatly hardened by the enormous pressure they have undergone, although the sandstones, slates and limestones constituting them (Fig. 117) were probably no harder originally than many of the rocks on the other side of our imaginary line.

Such hard rocks have resisted denudation to an extent which has left them towering above the more easily eroded sandstones, marls and clays which form the neighbouring pastoral lowlands of

Photo. Frith & Co.

FIG. 145.—Thorpe Cloud, Dovedale, Derbyshire. The illustration shows the picturesque results of the weathering of the Carboniferous Limestone, which varies considerably in the resistance it offers to denudation.

the Midland plain. Impressive as they still are, however, many of our mountains are now the mere stumps of what they must once have been. Even that prominent ridge the **Pennine Chain** is an anticline (p. 214), from the original summit of which the later and softer rocks (Coal Measures and, locally, lower Permian rocks) have been removed, exposing the harder and resistent part of the **Carboniferous** formations below. Of the Carboniferous rocks, the valuable **Coal Measures** are conspicuously marked in the geological maps, and their position here and elsewhere in Britain should be observed carefully. Reference to a population map shows a remarkable coincidence of coalfields and densely peopled areas, and emphasises, as scarcely anything else could, the part which

the coal supply has played in the development of our national industries (Chapter XVII.).

The greater part of our **mineral wealth**, it is to be noted, occurs in the old rocks. The hardest varieties among them are all eminently suitable for *building materials*, and the metamorphic rocks of Cumberland, Carnarvon and Cornwall furnish *roofing slates*. The coal measures yield not only *coal*, but also *iron-ore* and *clays* used for making bricks and pottery. The finest clay, known as *china clay*, however, is that which has been formed in Cornwall by the decomposition of granite. Ores of *copper* and *tin* also are found in Cornwall. *Lead* ore is found in Somerset (Mendip Hills) and in various parts of the Pennine Range.

The Midland plain.—Skirting the west, south and east of the Pennine Chain is shown on the geological map a considerable outcrop of beds marked **Trias** and, bordering this on the east, an irregular band of **Lias** runs across country from North Yorkshire to the shore of Lyme Bay. The relative softness of these formations—they consist chiefly of soft sandstones, marls, clays and shales—has given a characteristic appearance to the scenery. Easily eroded, they have weathered for the most part into flat expanses with stiff soils favourable for **pasture land**, over which flow long meandering rivers—the Trent, the Avon and others. Among the economic products of these rocks may be noted *building stones* of various qualities, the *salt* mines and springs of Cheshire and Worcester (p. 116), and a valuable bed of *iron ore* at Cleveland in North Yorkshire.

Escarpments and vales.—As we follow the succession of the rocks from the Lias eastward, we encounter in order the **Oolite**, the **Cretaceous** (*i.e.* chalk) formations, and the **Tertiaries**. The strata of the Lias slope to the east and south, and consequently dip under the more recently deposited Oolites (Fig. 146). The limestones of the lower (and older) Oolites are considerably harder than the friable Liassic rocks to their immediate west, and have withstood denudation to a much greater extent. The result is that the western border of the Oolites has weathered to a steep bluff called an **escarpment** (p. 208), which forms a more or less continuous line of high ground along the line of strike from the Yorkshire plateau * to Dorset. The escarpment is most pronounced in the Yorkshire Moors, the Lincoln Heights, the Edge Hills and the Cotteswold Hills.

*The term "plateau" is applied to an elevated plain which is surrounded on all sides by lower ground.

The Oolites of later date to the east of the escarpment are softer, and therefore have been worn down to a gentle slope of rich agricultural land in the direction of the dip (p. 213), *i.e.* to the east. The inclination of this "dip-slope" is so slight that in many regions the outcrop of the Oolites might almost be called a plain. On the whole, however, it forms a **vale** with a clayey soil

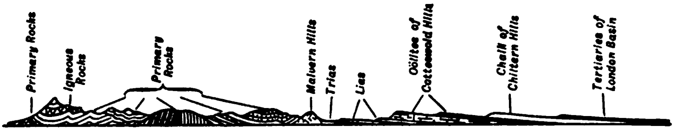


FIG. 146.—Geological section, approximately along a straight line between near Nevin (Carnarvon) and Woking (Surrey).

(the Vale of Aylesbury and the Vale of White Horse being included in it), along which flow the Nen, the Ouse and other rivers emptying into the Wash.

The eastern edge of the outcrop of the Oolites dips in its turn under the Cretaceous rocks (Fig. 146), the upper and newer formations of which (constituting the *Chalk*) are notably hard and durable. As a consequence, the great **Chalk Escarpment** runs across England in a course roughly parallel to the Oolite escarpment, though the two approach each other closely in Yorkshire and Dorset. Thus a range of heights, due to the relatively slow denudation of the

FIG. 147.—Geological section from Woburn through London to the North Downs, showing the syncline of the London Basin.

chalk, stretches from Flamborough Head, through the Wolds of Yorkshire and Lincolnshire, and the East Anglian Heights, to culminate in the Chiltern Hills and the Marlborough Downs. From the neighbouring chalk plateau which forms Salisbury Plain, the outcrop forks to the east to form the **North Downs** and the **South Downs**, and sends off a limb to the south-west which reaches the sea between Weymouth and Purbeck.

Between the Chiltern Hills and the East Anglian Heights on the northern side, and the North Downs on the southern side, the chalk forms a basin (Fig. 147); above it the syncline (p. 215)—called the **London Basin**—is occupied by beds of **Tertiary** formations. A somewhat similar **Hampshire Basin** forms a syncline between the South Downs and the chalk of Dorsetshire.

The Weald of Kent, Surrey and Sussex is a plain which is thus overlooked by chalk escarpments on the north, west and south. Its floor consists of Cretaceous rocks, older and softer than the

FIG. 148.—General geological section of the Weald and its relation to the North and South Downs. The dotted lines indicate the original strata which have been removed by denudation. (Adapted from the *Proceedings of the Geologists' Association*, 1897.)

chalk, which are arranged to form an anticline (p. 214). Evidently (Fig. 148) the chalk must once have extended as a dome above it, and have been removed by denudation. The rivers of the Weald still retain much of the original radial arrangement natural to streams draining a dome-shaped surface.

The topography of Scotland.—An orographical map shows that Scotland is divided physically into three main regions: (1) The Southern Uplands, (2) the Central Lowlands, and (3) the Highlands; and a map showing the character of the vegetation makes it clear that cultivated lands are practically confined to the Central Lowlands and a rim of varying width around the coast —widest on the east. Further, the population map shows a marked congregation of the inhabitants in the Central Lowlands.

The predetermining causes of these facts are again to be found on a geological map. On such a map the features of greatest significance are the following: The **Southern Uplands** (separated from the Pennine Chain by the "gap" of the Tyne,—the route, formerly of Hadrian's Wall and in modern times of the railway between Carlisle and Newcastle) form a broad **tableland** or plateau floored with Silurian rocks, which here, as in England, are hard and resistent and yield but poor soil. The northern edge of this region follows a fairly straight line, from Loch Ryan to Dunbar, which marks the position of a *fault* (p. 182). Another fault (the "Highland fault"), still more sharply defined, extends from Greenock to Stonehaven. The **Central Lowlands** lie between these two faults. The "lowland" character of the region is explained by the fact that the rocks—*Old Red Sandstone* and *Carboniferous* formations—although hard, are more easily "weathered" than those of the Southern Uplands and the Highlands; their degra-

dation also produces a more fertile soil. The Sidlaws, Ochils, Pentlands and Cheviots owe their rugged character to interbedded masses of *volcanic rocks*. The *Coal Measures*, finally, are in themselves a sufficient explanation of the density of the population in this part of the country. The **Highlands** are divided into the North-west Highlands and the Grampian Highlands by the *Caledonian Canal*, which lies along a line of disturbance of immeasurable antiquity (p. 217). The principal part of the Highlands consists of a great *plateau* of very old metamorphic rock called gneiss, which weathers with difficulty into a thin and inhospitable soil. Numerous outstanding masses of igneous rocks add to the impressive character of the scenery.

The topography of Ireland.—In Ireland a **central plain** occupies the larger portion of the country. The floor of the plain consists of *carboniferous limestone* covered with drift, and in a region so favoured by an abundant and equable rainfall, furnishes good pasture land.

To the north and south a greater variety of geological structure accounts for scattered groups of **hills** and **mountains**. Noteworthy features are the *volcanic rocks* forming the plateau of Antrim, the Mourne Mountains and the Wicklow Mountains, besides lesser heights; and the marked results of unequal sculpturing of the *Silurian* and *Old Red Sandstone* rocks of the east and south-east. The rarity of outcrops of the Coal Measures is associated with the industries and the uniform distribution of the population.

English river-systems in relation to topography.—The peculiar routes by which certain of our rivers flow from their sources to the sea are in themselves sufficient evidence that the surface-relief of our country has undergone a great change since England became "dry land." Most of our rivers are normal in taking a more or less direct course from source to mouth. There is nothing very strange, for example, in the general paths followed by the streams which have their sources on the slopes of the Pennine Chain, which indeed forms the northern part of the line—called the **watershed**—dividing the English rivers flowing into the Irish Sea from those flowing into the North Sea. Again, in the Lake District an "axis of elevation" can be traced from St. Bee's Head in an east-south-east direction; this, it is supposed, has been denuded to an extent of at least 2000 feet since it was first raised, but the

watershed is still sufficiently well marked to account for the flow towards the Solway Firth of the streams rising on its northern slope, and towards Morecambe Bay of those rising on its southern side. Further, the flow of such rivers as the Avon and the Trent along the "longitudinal" valleys which they and their own tributaries have excavated in formations lying between harder rocks, is what might have been expected.

But when we consider such rivers as the Tamar, the Exe, the Wye, the Severn, the Dee, and a branch of the Yorkshire Derwent,

Photo. Frith & Co.

FIG. 149.—Devil's Dyke, Brighton. A dry gap through the escarpment of the South Downs.

all of which rise close to the coast and then turn inland, ultimately to reach the sea at a considerable distance from their source, we are compelled to assume that the topography has undergone a marked change since the river began its career. Some, at least, of these cases are undoubtedly examples of **river capture** (p. 143), the original rivers having "cut back" so far as to divert to themselves some of the tributaries of streams flowing in quite different directions. It appears probable, from observations and considerations of this kind, that many of the present tributaries of the Severn formerly flowed into the Thames, and others, perhaps, into the Dee. "If this view is correct, the

Thames is an older, and was formerly a much larger river than the original Severn. The Severn began as a small brook which gradually ate its way back and, annexing the rivers of western Wales, cut them off from the Thames and deprived it of most of its head waters." * Also, there is evidence that the head waters of the present day Ribble have been captured from the Aire.

Even more interesting evidence of great change in topography is furnished by the **gaps** which rivers have cut through hard escarpments or other ridges. The estuary of the Humber is a striking example, and at Goring the Thames has also carved itself a gap through the chalk escarpment; the Medway and Stour have cut through the ridge of the North Downs, the Arun through that of the South Downs; other examples are mentioned on p. 238. Obviously such a river must have begun its activity before denudation had formed the escarpment, and must have deepened its bed at such a rate as to keep pace with the development of the escarpment and preserve the slope from its source to its mouth.

In cases, however, where the deepening of the bed fails to keep pace with the sculpturing of the ridge, the stream will be cut in two, the former head waters joining some stream on the other side of the "divide." Evidence of their previous continuity will remain, for a time, in the **dry gap** (Figs. 16 and 149) through the escarpment, at the common head of the two valleys.

The migration of watersheds.—The cases of the Thames and Severn, and of the Ribble and Aire, cited above, exemplify the fact that a watershed is no fixed line, but, like all other topographical features, is changing constantly. The main watershed of Britain—which divides rivers flowing into the North Sea from those debouching into the Irish Sea and Atlantic—lies nearer the west coast than the east coast, and the western slope is *therefore* steeper than the eastern. The western slope is also exposed to a heavier rainfall. For these reasons the rivers flowing westward will tend to cut back at a greater rate than those flowing eastward. In other words, the watershed as a whole is shifting gradually towards the east, at a rate varying with the softness of the strata. A watershed map of England (Fig. 150) shows that, as might have been expected, the line is moving eastward most quickly between the sources of the Avon and the Welland, where the rocks (Lias) are softer and more easily eroded than elsewhere on the "divide."

* Lord Avebury's *Scenery of England*, p. 374 (Macmillan).

In north Wilts, the main watershed divides near the source of the Salisbury Avon, one of its branches passing east to the South Foreland and the other west to Land's End. This line of high

FIG. 150.—River basins and watersheds of England and Wales.

land, south of which all rivers flow into the English Channel, has been cut back to the greatest extent by the Tamar, the Exe and the Salisbury Avon.

River valleys as means of communication.—"Dry" gaps, as well as the valleys through which rivers still flow, form a valuable

means of communication between regions separated topographically by high land. A well-known example is the dry gap, 300 feet deep, through the Chiltern Hills between Aylesbury and Amersham. Other gaps through the Chiltern Hills, of which advantage is taken for **railway routes**, are the Lea gap at Luton (Midland Railway) and the Berkhampstead dry gap (London and North-Western Railway). Equally interesting are the Wey gap through the North Downs at Guildford (London and South-Western Railway), the Itchen gap through the South Downs at Winchester (London and South-Western Railway), and the gap joining the valleys of the Kennet and the Avon, crossed by the Great Western Railway.

It is instructive to follow, on an orographical map, the main railway lines to Scotland, and observe how and to what extent they respectively utilise river valleys to evade the difficulties of mountainous districts. North of the Tees the North-Eastern Railway follows the coast to Berwick, with a branch line through the Tyne gap from Newcastle to Carlisle. The Midland Railway, beyond Leeds, takes advantage of the valleys of the Aire and the Ribble to reach the watershed of the Pennines, which it follows to the head of the Eden valley; this valley leads directly to Carlisle. The London and North-Western Railway keeps to the west of the Pennines, and reaches Carlisle *via* the Lune valley and Shap Fell.

Even more markedly dependent on river valleys are the Scottish railway lines diverging from Carlisle. The Caledonian Railway crosses the southern uplands by way of Annandale and Clydesdale; the North British Railway utilises in succession the valleys of the Liddel, the Teviot, the Tweed, and Gala Water; while the Glasgow and South-Western Railway reaches Ayrshire, and therefore obtains ready access to Glasgow, by an easy gradient up the valley of the Nith.

It need scarcely be added that all these routes were used as highways of communication long before the days of railroads.

Lakes.—Hollows in the surface of the land which have become filled with water are known as **lakes**. They vary in size from that of Lake Superior, the largest fresh-water lake in the world, of about the same area as Ireland, to the tiny ponds occurring everywhere. Lakes may be divided into classes, either according to

their composition into fresh or salt, or according to the way in which the depressions in which their water has accumulated have been formed. No classification of lakes is altogether satisfactory, and there is much diversity of opinion on the subject. Some authorities, for instance, divide lakes into classes depending upon their situation, others regard the fact of lakes having streams running in or out of them, or both, as being the important matter; but whatever system of classification is adopted, it is of importance that the student should know some of the causes which have helped in the formation of lakes.

The suspended materials brought continuously into many lakes by rivers flowing into them tend gradually to silt up and obliterate them. Judged in connection with rivers, lakes may be regarded **as temporary modifications of the rivers.** The heads of all our lakes show flat plains, formed of deposits laid down by the rivers which are flowing into them and gradually filling them up (Fig. 98). Because of this tendency to their obliteration, lakes in general must be of recent geological origin.

As a typical method of classifying lakes, one depending upon the nature and origin of their basins may be described:

1. *Lakes of which the basin has been formed by underground movements of the earth's crust.* It has been learnt already that movements of this kind have had other important effects in the production of mountain ranges, in causing volcanic eruptions and earthquake disturbances, and in bringing about changes of level in the earth's surface. These great earth-movements have assisted in the formation of many of the great lakes of the world, such as the Dead Sea and those of the St. Lawrence basin. Lough Neagh in Ireland may be mentioned as a lake basin formed by subsidence, and the Cheshire "meres" and many small lakes in limestone districts owe their origin to the collapse or settling of the surface of the earth following on the removal of deeper rocks by solution. *Crater lakes* may be included under this heading.

2. *Lakes caused by irregularities in the deposition of accumulations on the earth's surface*, prior to the elevation of the land; or, in the northern parts of Europe and America, during the disappearance of the great ice sheet, which in the glacial period of geological time covered this part of the world. Most of the small and shallow lakes and *tarns* of the lowlands of the North of England, of Scotland, and of Ireland, have probably been caused by water filling hollows formed in this way. These lakes are enclosed by mounds and ridges of "drift" clay and gravel

deposited by glaciers, which existed above them in some previous geological age.

3. *Lakes caused by the accumulation of barriers across river valleys, and the consequent ponding back of the water.* Such a barrier may result from a "land-slip," from a bank thrown up by the sea across a river's mouth, by a lava stream, or from the passage of a glacier transversely across a valley. Among the commonest of such barriers are the moraines of ancient glaciers, which, being deposited transversely to the direction of

Photo. Photochrome Co.

FIG. 151.—The Märjelen See. A lake dammed by the Aletsch glacier.

a valley stream, dam the water and form a lake. Loch Mōr (Fig. 152) and the Märjelen See (Fig. 151) are good instances of this. Many of the lakes of Wales and North-West England have been formed in this manner.

4. *Lakes resulting from erosion.* This erosion has been brought about either by the prolonged action of glacier ice, or by the unequal denudation resulting from the action of the weathering influences described in Section **25**. Wales, Scotland, Switzerland, Scandinavia and North America all present many examples of what are called "Alpine" and "sub-Alpine" lakes, and all of these countries in an increasing degree have been subjected to glacial action. But lake basins are eroded sometimes by agencies other than ice. Rain, wind, frost, and so on, may cause some

rocks to break up at a more rapid rate than others in the neighbourhood, and when the debris formed has been removed a sufficient depression results to lead to the formation of a lake basin.

Coast-line features of Britain.—It has been seen (p. 128) that marine denudation has played only a minor part in the development of the present coast lines of our country. Nevertheless,

FIG. 152.—Moraine dammed loch, Loch Mōr, Ben More Assynt. (Photographed by the Geol. Survey of Scotland.)

certain well-marked features of the coast line are to be attributed to the sculpturing of the land by the ocean.

Naturally, the extent of this erosion will depend as well on the softness of the rocks constituting the cliffs as on the violence of the seas. It would be to the western coasts of Ireland, Scotland, and some parts of England and Wales (Fig. 142) that one would naturally go for the best examples of this kind of work, for it is

there that the rocks are exposed to the full fury of the Atlantic waves. At the same time, since, generally speaking, the rocks on the east coast are much softer than those of the western shore line, the *rate* of erosion is there much greater than in the west counties. Some parts of the coast of Yorkshire and Lincolnshire are said to be worn away at the rate of three feet per year, while on the western coast there would not be this amount of erosion in a century.

"There can be no doubt," says Lord Avebury,* "that formerly the chalk stretched across the mouth of the Wash from Hunstanton to Lincolnshire, with an escarpment to the west overlooking a plain. . . . This chalk ridge gradually became narrower, . . . and it was no doubt intersected by the Witham, the Welland, the Nen, and the Ouse. . . . By the enlargement of the estuaries, and the existence perhaps of a slight synclinal depression, the chalk was reduced to islands, and finally removed entirely. The area to the south-west of the chalk consisted of soft clays. These could offer no effective resistance, and the denudation of the land proceeded rapidly, reducing it to a low plain, the future Fenland. The process continued until the waves were stayed by the harder Oolites. . . .

"'The Wash, therefore,' says Skertchley, 'is not an estuary but a **bay**; it is not the seaward continuation of a river channel—a breach of the coast from the land side—but an indentation of the land by the sea—a breach of the coast from the sea side.'"

EXERCISES ON CHAPTER X.

1. If the sea level rose 600 feet all the lowland parts of Great Britain would be submerged. Describe shortly, or show by a sketch, what the map of Great Britain would then be like. (O.J.)

2. Describe the result of submerging England and Wales to a depth of 600 feet. (O.H.L.)

3. In some parts of the British Isles the surface consists of limestone or of chalk. State the positions of some of these parts, and point out any peculiar features about the rivers which flow over them. (O.S.)

4. Explain the terms watershed and river basin, and give examples from England and Ireland. (L.C.C.)

* *The Scenery of England*, p. 454.

5. Describe the water parting (watershed) of the Thames basin, and point out where it runs along ridges. (L.J.S.)

6. How would you describe the distribution of chalk and chalk escarpments over the S.E. of England? What effects on the life and industries of the people may be traced to this distribution? (L.J.S.)

7. Describe the conformation of the highlands of England which divide the rivers flowing into the eastern, southern and western seas. (O.J.)

8. Discuss carefully the position and the character of the chalk ranges of England east of 1° W., showing their past and present importance. (L.M.)

9. "Great Britain should be divided into its natural regions as determined by the relief of the land, and each region should be treated separately." Draw up a short scheme of lessons based on this statement. (Cert.)

10. Describe the physical features of Ireland *north* of a line drawn from Limerick to Dublin, and illustrate your answer by means of a sketch map. (C.S.)

11. Describe (*a*) the relief, (*b*) the river system, (*c*) the positions of the towns, of the region comprising the North and South Downs and the Weald. (C.S.)

12. Describe carefully the original *Great Western Railway* route from London to Exeter, showing clearly how it was influenced by the relief. (L.M.)

13. Describe the distribution of the lakes of the British Isles, and show how one of them was formed. (J.B.M.)

14. Contrast the Highlands with the Central Plain of Scotland. Consider both the physical conditions and the human activities, and give detailed information as far as you can. (J.B.M.)

15. What river basins are contiguous to the basin of the Severn? Describe the character and position of the watershed in each case. (J.B.M.)

16. Describe carefully the relief of the six northern counties of England. Point out how it has determined the most important railway routes. (J.B.M.)

17. Name the coalfields of the British Isles, and in the case of two of them explain their relation to the geological structure. (J.B.M.)

18. What types of land-forms are illustrated by any *three* of the following: the Pennine Chain, the Cotteswolds, the Weald, the Lincoln Gap, the Central Lowlands of Scotland? (J.B.M.)

19. The rivers of England and Wales may be grouped into three systems. Indicate what physical features constitute the water partings, and compare the configuration and industries of the three regions thus drained. (Prel. Cert.)

20. Indicate the important differences between the conformation of the hills of S. and S.E. England and those of Wales and the Lake District. (P.T.)

21. Describe the structure and configuration of England south-east of a line passing through Exeter, Bristol, Rugby and Goole at the mouth of the Yorkshire Ouse. (N.F.U.)

22. Describe briefly the general arrangement of the drainage systems of the scarp-lands of England. Give instances of striking exceptions to this system and try to explain them. (J.B.M.)

23. Describe the characteristic features of a cave in a limestone region, and explain how such caves are formed.

CHAPTER XI.

THE OCEAN AND ITS MOVEMENTS.

27. THE PROPERTIES OF SEA WATER.

1. **Taste.**—Taste a little sea water. Of what does it remind you? Would you describe the taste as sweet, bitter, salt, sour, or a combination of any of these?

2. **Dissolved matters.**—Evaporate over a water bath (Fig. 78) a measured quantity of sea water in a porcelain dish, or in a saucer over water boiling in a saucepan. Observe (*a*) the escape of bubbles of *gas* as the sea water becomes hot. Notice that these bubbles are not steam, because after the water is quite hot no more bubbles escape, although steam is given off continually until the contents of the saucer are dry.

(*b*) Note the residue of *solid matter*, which was formerly in solution. What is its appearance? If possible, weigh the dish and residue, and afterwards the dish alone, and calculate the amount of dissolved solid matter in grains per gallon or in grams per litre. Expose the residue to the air for twenty-four hours, and then re-weigh to see if it has absorbed moisture from the air. Taste the residue. To what is the taste of sea water due?

Treat river water in the same way and compare the results.

3. **Density.**—Weigh a bottleful of distilled water, and then the same bottle filled with sea water at the same temperature. Which is heavier?

Composition of sea water.—The character most commonly associated with sea water is its *saltness*, and this is due to the presence of salts dissolved in it. When the great solvent power of water is borne in mind, and it is remembered that there is a continual addition to the ocean by the streams and rivers which run into it in all parts of the world, all of them bringing samples of the rocks through which they have percolated, and that from the surface of the ocean a continual evaporation is going on,

removing pure water and leaving the dissolved substances behind, it is not difficult to form some idea of how the saltness of the ocean is brought about. Side by side with this process, which would result in the continual increase in the amount of dissolved material, there is, however, a withdrawal of certain of the soluble ingredients by living organisms, both plant and animal, some of which extract calcium compounds, others silica, wherewith to build up their solid parts (p. 197). There is a greater tendency, therefore, for some of the dissolved compounds to increase than for others. This increase may go on in the case of the sodium chloride and calcium sulphate, until by-and-by the water can hold no more; it becomes *saturated*, and there is a precipitation of such compounds, forming a deposit.

Moreover, from our knowledge of the nature of the plants and animals which have lived in the ocean in past ages of the world's history—information obtained from the fossil remains of such living things—there is every reason to believe that the ocean has been similarly salt since the earliest times of the life record.

Though the composition of the ocean is, on the whole, wonderfully uniform, there are slight variations easily explained by local conditions; for example, where the evaporation is much greater than the average, as in the region of the trade winds (p. 250), the percentage of dissolved material is appreciably higher. On account of evaporation also, the surface water of the ocean is sometimes salter than that below. Again, when there is a continual great addition of fresh water, as near melting icebergs, near the mouths of large rivers, or near a coast having excessive rainfall, the ocean water becomes less salt.

A typical specimen of sea water contains approximately three and a half per cent. of dissolved salts, that is to say, if 100 pounds of sea water are taken and evaporated to dryness, a residue weighing three and a half pounds is left behind. This residue is made up of a variety of substances, present to the extent shown in the following table:

Sodium Chloride	2·700
Magnesium Chloride	0·360
Potassium Chloride	0·070
Calcium Sulphate	0·140
Magnesium Sulphate	0·230
Calcium Carbonate	0·003
Magnesium Bromide	0·002
	3·505

Much can be learnt from a consideration of this table. First, a large part of the total solids is made up of common salt. From the fact that every hundred pounds of sea water contains between two and a half and three pounds of common salt, some conception may be formed of the enormous amount of this compound there is in the whole ocean. Though the amount of calcium sulphate is only one-seventh of a pound in one hundred pounds of sea water, yet this amount is sufficient to furnish the lime for the marine animals which possess shells and other hard parts composed of calcium carbonate (p. 197).

Gases dissolved in sea water.—Rain, from which the waters of the ocean are of course altogether derived indirectly, dissolves from the air through which it passes samples of the gases contained therein, and the continual contact of the atmosphere with water surfaces, whether those of rivers or of the ocean itself, results in a further solution of different gases. Finally, the carbon dioxide which results from the breathing of the animals of the ocean is continually being added, as well as that given off by submarine volcanoes. The result is that sea water contains from about two to three per cent. of its volume of dissolved gas. This amount is made almost entirely of oxygen, nitrogen and carbon dioxide. One half the total amount of these gases consists of nitrogen, while the other mostly consists of oxygen and carbon dioxide in about equal proportions. It is interesting to note that, while the oxygen occurs in larger proportions near the surface, the carbon dioxide is present to the greatest extent deep down.

Density of sea water.—Since sea water contains the amount of dissolved material already mentioned, it is heavier, bulk for bulk, than fresh water. If a vessel which at 4° C. exactly holds one pound of pure water is taken and filled with water from the North Pacific Ocean it is found to hold 1·0254 lbs.; if water from the Red Sea is used, its weight is found to be 1·0279 lbs.; while the same volume of North Atlantic water weighs 1·0266 lbs. The numbers are thus nearly the same wherever the water is obtained, and since the chemical composition is nearly constant it follows that the density varies little, one being dependent upon the other. By performing a large number of experiments on this plan and taking the mean of all the results, the number 1·0275 has been obtained, and is spoken of as the *mean density of sea water*.

Since the deeper we descend into the ocean the greater becomes the height of the water column above us, it is clear that depth and pressure increase together. Though water is only compressed slightly by a great increase of pressure, yet its molecules do become packed a little more closely together at greater depths,

and the effect is seen by an increase in the density of the water. The density of the surface water has been found to be 1·0247, while water at a depth of a little more than two miles had, in one case, a density of 1·0525.

Freezing point of sea water.—Sea water freezes at a lower temperature than fresh water, but the ice formed is nearly fresh, for in freezing a large proportion of the salts is left behind. The temperature at which ice begins to form is from $-2°$ C. to $-4°$ C. The temperature of freezing varies a little with the amount of material dissolved in the water. Experiments show that if a solution of sodium chloride is cooled sufficiently, pure ice separates first at a temperature lower than the freezing point of pure water, and that if the cooling is continued, at $-22°$ C. the whole solution freezes, forming a crystalline substance.

Colour of sea water.—The colour of the ocean is variable from place to place, but generally in the open sea where the water is very deep it has a beautiful blue tint. When the water is shallower the colour passes from blue to shades of green. Several suggestions have been made to explain these colours, but it is quite satisfactory to regard the hue as belonging to the water itself. Pure water seen through a great thickness is quite blue in appearance. Should impurities which are not dissolved, that is, substances simply held in the water in *suspension*, be present, the water may assume other tints, *e.g.* parts of the Pacific Ocean are of a red colour, due to the presence of minute animals; the Yellow Sea gets its name from the fact that it has been so coloured by sediment brought down by rivers; the Red Sea is said to derive its name from a microscopic plant of that colour which is present in large numbers.

28. CURRENTS IN THE OCEANS.

1. **Currents due to wind.**—Blow with bellows on the surface of muddy water in a glass tank. What depth of current can you produce without spraying up the water from the surface?

2. **Currents due to varying density.**—Place a piece of ice in a trough of water *ABCD* (Fig. 153), and at the other end of the trough arrange a metal rod *E*, kept hot by a flame *F*. Pour a little coloured water (*e.g.* red ink) into the trough, and notice the general movement of the water.

3. **Study of ocean-current maps.**—From a map of the world showing ocean currents (Fig. 154) answer the following questions: What is the *general* direction of the current in the equatorial part

of the Atlantic, of the Pacific Oceans? Is the direction the same as that of the earth's rotation? Name any wedge-shaped land mass interposed in the path of the equatorial current of the *Atlantic.* In what manner is the direction of the current thereby modified? What becomes of each branch? Does either branch divide again? Can you suggest a cause for the division? Do the currents of the Atlantic show any resemblance to whirlpools or *eddies*? Describe any Atlantic eddies as *clockwise* if the direction is like that of the hands of a watch lying face up, or *anti-clockwise* if the opposite. What currents in the Atlantic flow from polar seas towards the equator?

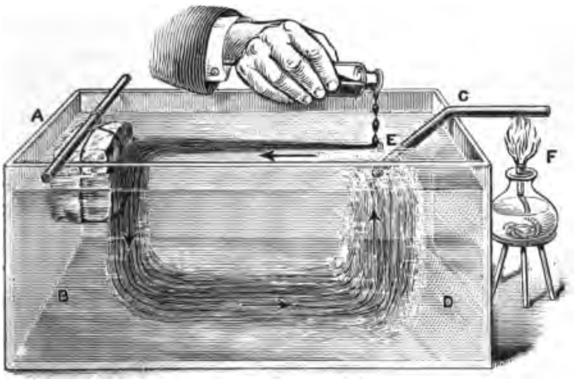


FIG. 153.—Circulation of water.

Into what branches does the westward equatorial current of the *Pacific* divide? Suggest a cause for the division. Does either branch divide? Why? How many eddies are to be seen in the Pacific? Describe the course of any currents flowing into the Pacific from polar oceans.

What is the general direction of flow in the Antarctic Ocean? Do the currents form an eddy? What is the projection (Chapter III.) of your map? If the Antarctic currents were shown on a polar projection, would they appear as an eddy? If so, would the direction of flow be clockwise or not, coincide with the earth's rotation or not? If possible examine the course of the Antarctic currents on a globe.

Ocean currents.—Several causes are at work tending to produce movements in the waters of the oceans, but it is most probable that the **prevailing winds** constitute the chief motive force

resulting in the production of the great *regular* movements of the water referred to under the term **ocean currents.** In this connection the comparative shallowness of the ocean (p. 129) must be again insisted upon, for it is only by bearing this in mind that any conception of the power of the wind can be attained.

The principal ocean currents.—North and south of the equator, blowing with unceasing regularity, occur the systems of air currents known as the **trade winds** (Chapter XIV.). In the northern hemisphere these winds blow between latitudes 6° N. and 35° N. from the north-east to the south-west; while in the southern hemisphere they blow throughout corresponding latitudes from the south-east towards the north-west. The consequence is that they meet in the neighbourhood of the equator, and the resultant wind, acting upon the waters, causes the latter to move towards the west. Were there no land masses to interfere with its course, a great equatorial current round the earth would be produced. But the continents of South America and Africa extend in a northerly and southerly direction, that is, at right angles to the path of the current, and prevent its continuous course round the globe, causing it by coming into contact with the land to divide into the various currents which will be described immediately.

Secondary causes assisting in the formation of ocean currents are:

The *rotation of the earth*, which causes a body of water moving polewards to have a tendency in an easterly direction, and one moving towards the equator a tendency towards the west.

Any change in the *extent of the polar ice caps* modifies local currents. Such modifications are most pronounced in the southern hemisphere, where several currents are indirectly affected.

Evaporation and *precipitation* of water must also be mentioned. Their effect on the great ocean currents is small. With the water brought in by rivers, they are the chief cause of the currents noticed in inland seas and in the straits that connect them with the ocean.

Temperature inequalities and *differences in atmospheric pressure* also exert some influence in the formation of ocean currents, but, compared with the effect of the winds, their work in this direction is almost negligible.

In inland seas, however, differences of atmospheric pressure are sometimes of importance, giving rise to disturbances of the water known as *seiches*.

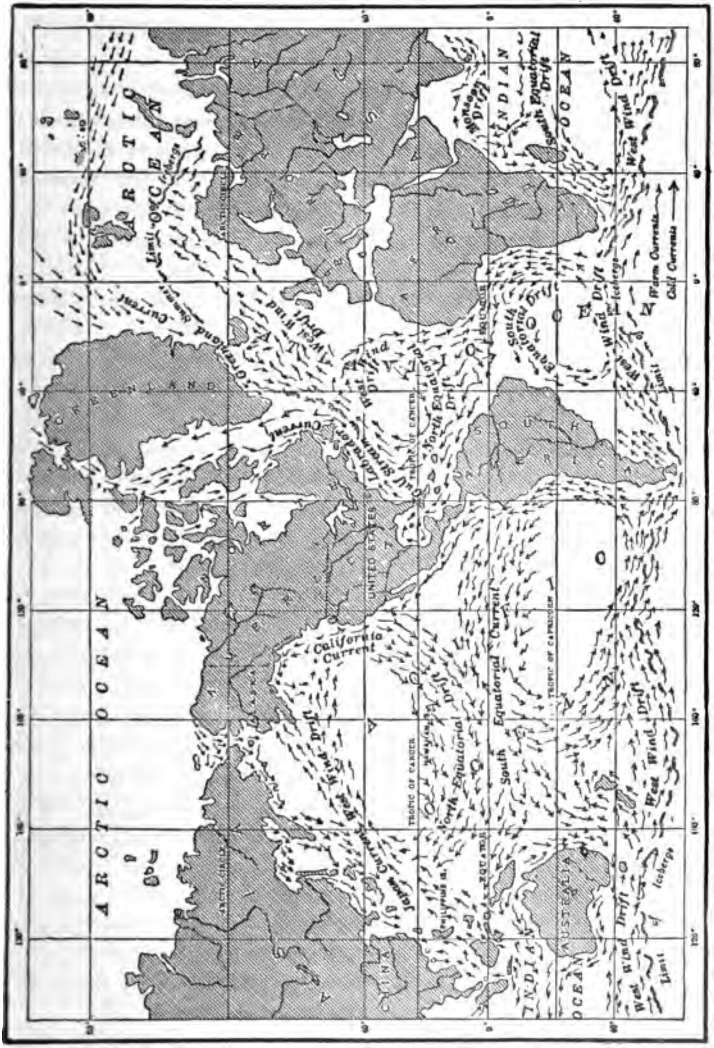


FIG. 154.—Map of Ocean Currents. (Adapted from Tarr's *Physical Geography*, Macmillan.)

The following account of the principal ocean currents is based upon a summary by Mr. W. J. Humphreys, published in the Meteorological Chart of the North Pacific Ocean, January, 1911, of the U.S. Weather Bureau.*

North Atlantic.—The *North Equatorial Current* is driven by the trade winds across the Atlantic. This **warm current** has a velocity of about 15 to 25 miles a day. Reaching the coast of South America, part passes north. The greater portion of this reaches the Caribbean Sea and eventually becomes the *Florida Current*, the name given to the eastern current flowing along the north coast of Cuba. Being diverted to the north-east, the Florida Current becomes the important **Gulf Stream**, one of the swiftest and most important of the ocean currents. Off the coast of New England the Gulf Stream turns due east, the direction of the prevailing winds, and flows on until about half-way across the Atlantic. Here, at about long. 40° W., lat. 42° N., this great warm current fans out into a broad slow current that covers the ocean from Spain to Iceland and extends round Norway to Spitsbergen and Nova Zembla. This extended continuation of the Gulf Stream is known as the *Gulf Stream Drift*. The wind which determines the direction of the Gulf Stream Drift is warm and moisture-laden, and this air tempers the climates of the British Isles and other countries, the windward sides of which are bathed by the drift. The temperature of the water itself differs but very slightly from that of the land.

Besides the warm currents enumerated, the North Atlantic includes three important **cold currents**: The *East Greenland Current* flows from the Arctic Ocean in a south-westerly direction along the east coast of Greenland, and eventually turns north-west into Davis Strait. The *Labrador Current*, a continuation of the East Greenland Current, flows south of the coasts of Labrador and Newfoundland, and disappears as a surface current at the northern edge of the Gulf Stream. The *Canary Current* (or *West Wind Drift*), which is cold for its latitude, flows south and south-west between the Sargasso Sea (p. 255) and the west coast of Africa.

South Atlantic.—A slow moving current of cold water crosses the

* Reprinted in *The School World*, January, 1911.

Atlantic between lats. 40° and 60° S. from west to east in the direction of the prevailing winds under the name of the *West Wind Drift.* Much of the West Wind Drift turns north off the west coast of South Africa and continues as the *Benguela Current*, which is cold for its latitude. The Benguela Current, under the influence of the trade winds, turns westward and crosses the ocean as the *South Equatorial Current.* Approaching South America, it divides near Cape St. Roque into a northern and southern portion; the first merges into the North Equatorial Current, and the second flows along the south-east coast of Brazil as a warm current known as the *Brazil Current.*

North Pacific.—Corresponding to the currents in the North Atlantic Ocean, we have here a *North Equatorial Drift* flowing under the influence of the trade winds as a broad **warm** current, with a velocity of 12 to 20 miles a day, all the way from the American coast to the Philippine Islands. Just north of the equator an irregular current of varying width is found flowing east, counter to, and between, the north and south equatorial currents; it is the *Counter Equatorial Current.* It is about 300 miles wide near America, and tapers to a wedge near the Philippines. The greater part of the north equatorial current passes north under the name of the *Kuroshiwo*, or *Japan Current.* The Japan Current is narrow and swift, and corresponds to the Gulf Stream. It eventually spreads out, and, following the direction of the prevailing winds, flows east to North America, where, with the northern part of the North Equatorial current, it becomes the somewhat **cold** *California Current.* A cold current also flows south-west from the Bering Sea along Kamchatka to Japan.

South Pacific.—As in the South Atlantic, a **cold** Antarctic (West Wind) Drift Current flows eastward across the Pacific between lats. 40° and 60° S. A large part of it turns north off the coast of South America, and becomes known as the *Peru Current.* The Peru Current near Cape Blanco takes a westerly direction, and, following the direction of the trade winds from South America, crosses the Pacific Ocean to about long. 180° as the *South Equatorial Current.* Part of the last-named current, passing among the Pacific Islands, turns south along the south-east coast of Australia

as the *East Australian Current*, which eventually merges with the Antarctic Drift.

Indian Ocean.—The Antarctic Drift Current is in evidence in the Indian Ocean also; part of it turns north near the south-west corner of Western Australia, becoming the *West Australian Current.* The trade winds give rise to a *South Equatorial Drift* flowing west from Australia to the north of Madagascar; part of this takes a southerly direction off the east coast of Madagascar, and merges with the Antarctic Drift. During northern winters nearly all, and during southern winters still a portion, of the south equatorial current reaching the north of Madagascar turns south near the African coast, which it follows as a warm current, first under the name *Mozambique* and then *Agulhas*, round the southern extremity of Africa. A south-west **Monsoon Current** flows only during the northern summer, when most of the South Equatorial Current turns, near Madagascar, and flows north-west along the African coast under the influence of the south-east monsoons, and then east by way of Ceylon to Sumatra. During the northern winter the monsoons are from the north-east (Chapter XIV.), and during this time there is a surface current from Sumatra westward to the coast of Africa.

The ocean currents considered as systems of vortices.—An examination of a map showing the ocean currents reveals the fact that the currents can be arranged into groups, each forming a huge vortex with comparatively still water in its centre. Thus, if the course of the following currents in the North Atlantic, viz. the Equatorial, Guiana, Gulf Stream and Guinea is traced, it will be seen that they form a complete cycle, the currents constituting the circle all moving in the direction of the hands of a watch or "clockwise," and forming a right-handed vortex. Conversely, the Equatorial and the Brazil currents with the northward-moving cold water from the Antarctic which passes up past Cape Colony along the west coast of Africa, together make up a left-handed vortex, or one moving in the opposite direction to the hands of a watch, *i.e.* "anti-clockwise."

In the Pacific Ocean, too, the Equatorial and the Japan currents, with the continuation of the latter down the west coast of North America, can all be considered as making up a right-handed vortex or a system of currents moving in a clockwise manner in the North Pacific; whereas the Equatorial and New

South Wales currents with the colder Antarctic drifts all move in an anti-clockwise manner, forming a left-handed vortex in the South Pacific.

The central part of each of these vortices is comparatively still water, and its existence is marked by a luxuriant growth of seaweeds, including one, the *Sargassum bacciferum*, from the presence of which the still area of the North Atlantic is called a **Sargasso Sea.** Within this region there is also an abundant animal life. Probably these seaweed-covered districts have supplied many of the oft-reported sea-serpents, for to an imaginative mariner at a distance the gentle up and down movements of water thus covered could be construed easily into the serpentine movement of some huge sea-monster.

Temperature.—The general effect of heat upon liquids is to make them expand, causing a given mass to occupy a larger volume and so become lighter, bulk for bulk. The heating effect of the sun in tropical regions, therefore, causes a rising of the lighter waters, and a sinking of the heavier colder waters of "higher" latitudes to take their place.

The general result of a difference of temperature in equatorial and polar regions is that there is a tendency for a warm surface current to flow into higher latitudes. This becomes sufficiently cooled, by its arrival at lat. 60°, to sink. Also a cold current of fairly fresh water, formed by the melting of icebergs, creeps along the surface from the poles towards the equator, but sinks about lat. 60°. This action can be illustrated experimentally (Fig. 153).

29. THE TIDES.

1. Interval between successive times of high water.—(*a*) *Outdoor work.*—At any seaside place possessing a tide gauge or other convenient scale of feet, observe as nearly as possible the time of high water day after day. How does your estimate agree with the expected time of high water as announced for the day? What is the interval between high water from day to day? Is it always the same?

(*b*) Consult *Whitaker's Almanack* or some other convenient source of information and find out the intervals between successive times of high water at any place for a month. Are they always the same? What is the average of the intervals?

2. Interval between successive southings of the moon.—Find the intervals between successive southings of the moon (given in

Whitaker's and other almanacs) for a month. Are they always the same? What is the average interval? How does it compare with the average interval between successive times of high water?

3. Spring and neap tides.—(See tables on pp. 260 and 261.) On what dates was the range between high and low water (*a*) greatest, (*b*) least at Portsmouth during September 1909? How do these dates agree with the phases of the moon in the same month? Is a similar agreement to be seen between the moon and tides during June 1909? In each month the tides with a greater range than usual between high and low water are called *spring tides*; those with a smaller range than usual are called *neap tides*. What sort of tides is evidently to be expected at new moon, first quarter, full moon and last quarter respectively?

Have spring tides the greater range in June or in September?

4. Establishment of ports.—*The time of high water at any port on the day of new or full moon is called the establishment of the port.* (*a*) Look up in *Whitaker's Almanack* the time of high water at London Bridge which occurs next after the hour of new moon in each month. Take the average of these 13 times of high water to find the establishment of London Bridge. Similarly, find the establishment of London Bridge from the times of high water next following full moon. How do the two results compare?

(*b*) From the almanac find out if there is any constant, or nearly constant, interval between the times of high water at London Bridge and Liverpool day by day for a month. Compare the average interval with that in some other month. What is the establishment of Liverpool? Obtain it directly as in (*a*) and compare the results.

(*c*) Find out similarly the establishments at Bristol, Hull, Greenock, Leith and Dublin. Mark the seven establishments on a map and compare it with Fig. 162.

(*d*) *To find the approximate time of high water at any place on any date*: To the time of the moon's southing on that date add the establishment of the port. Using the establishments given on p. 263, find in this manner the time of high water at Harwich, Whitby, Swansea and Holyhead on the day of new moon at Easter of the year of your copy of *Whitaker's Almanack*. Compare your results with Fig. 162.

5. Study of tide chart.—(*a*) *Cotidal lines.*—Examine Fig. 162. How long does it take a tide wave to travel from the west coast of Ireland to (i) Liverpool, (ii) Hull, (iii) the mouth of the Thames?

Trace the progress of the tidal wave from Galway to the Mull of Galloway.

At what places shown on Fig. 162, and at what approximate times on the day of full moon, do two tide waves meet?

Compare the times of high water at Dover and Liverpool.

(*b*) *The set of tidal streams.*—Examine Figs. 155 and 156. At what places are the directions of neighbouring streams sharply contrasted? Make notes of the directions and speeds of the tidal streams at the following regions, (i) when the water is falling at Dover and Liverpool, (ii) when the water is rising at Dover and Liverpool: Off the mouth of the English Channel, off the south coast of Ireland, in St. George's Channel, in the Bristol Channel, in the Gulf of St. Malo,* east and west of the Straits of Dover, off Valentia Island, along the west coast of Ireland, in the North Channel, between the inner and outer Hebrides, along the north coast of Scotland. How do the tidal streams differ in direction at any (the same) time along the east coast of Great Britain?

Where, round the British Isles, do you suppose such charts are likely to be of the greatest value to seamen? Why?

Phases of the Moon, June 1909.

	D.	H.	M.	
Full Moon - -	4	1	25	Morning.
Last Quarter - -	11	2	43	Morning.
New Moon - -	17	11	28	Afternoon.
First Quarter - -	25	6	43	Afternoon.
In Perigee - -	12	4		Afternoon.
In Apogee - -	25	0		Noon.

Phases of the Moon, September 1909.

	D.	H.	M.	
Last Quarter - -	6	7	44	Afternoon.
New Moon - -	14	3	9	Afternoon.
First Quarter - -	22	6	31	Afternoon.
Full Moon - -	29	1	5	Afternoon.
In Perigee - -	1	7		Morning.
In Apogee - -	16	9		Morning.
In Perigee - -	29	5		Afternoon.

N.B.—The times given in the foregoing tables, and in those on pp. 260 and 261, are for Mean time at Portsmouth; if Greenwich or Railway time be required, *add* 4 minutes.

* "A return of the vessels wrecked on the Channel Islands shows that the greater part of them ran ashore about the end of the falling water at Dover."

General observations.—Everyone must have noticed when at the seaside that during every day there are what are known as

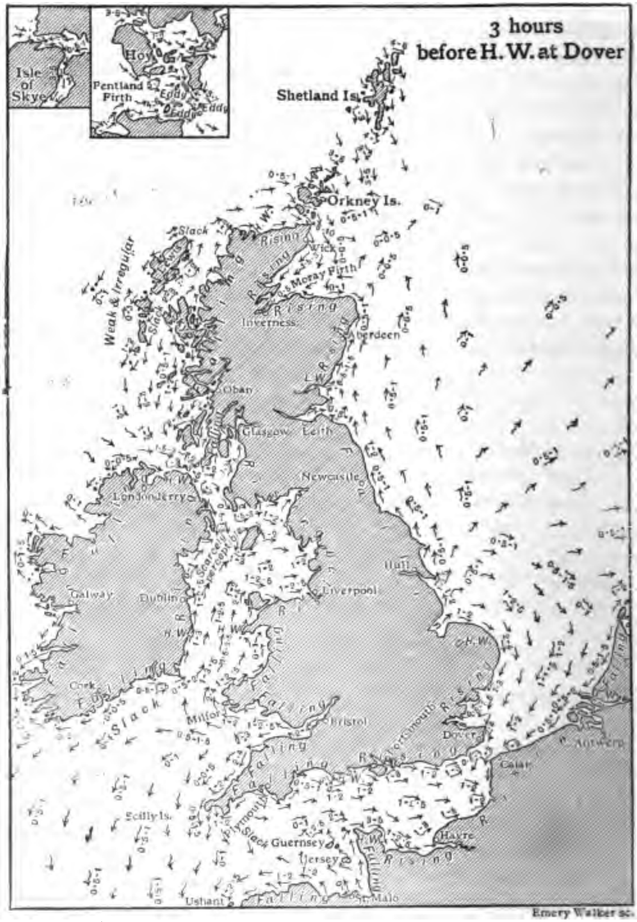


FIG. 155.—Chart of tidal streams 3 hours before high water at Dover. (Speeds are given in knots, that is, nautical miles per hour.)

two "high waters" and two "low waters." The former are called "high tides," and the latter, "low tides." Moreover, when

the height of the water is increasing, or when low tide is giving place to high tide, it is a *flood tide*; whereas when the high tide

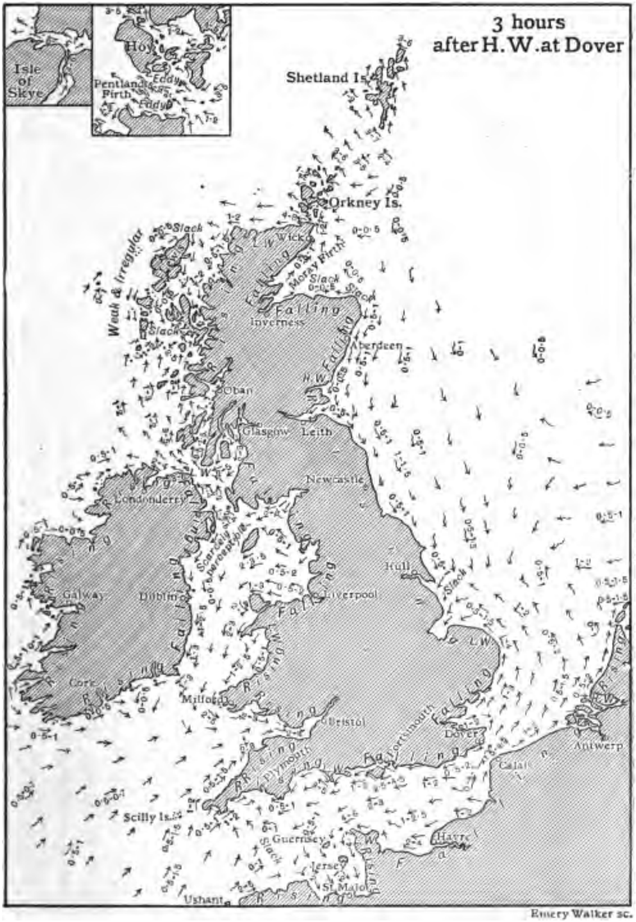


FIG. 156.—Chart of tidal streams 3 hours after high water at Dover. (Speeds are given in knots, that is, nautical miles per hour.)

has been reached and the height of the water is becoming lower—as the low tide is approached—we have the *ebb tide*. The sloping

TIDE TABLES FOR JUNE, 1909.

PORTSMOUTH (*H. M. Dockyard*).

Week Day.	Month Day.	High Water.				Low Water.			
		Morning.		Afternoon.		Morning.		Afternoon.	
		Time. H. M.	Height. F. I.	Time. H. M.	Height. F. I.	Time. H. M.	Height. F. I.	Time. H. M.	Height. F. I.
Tu.	1	9 44	11 2	10 4	12 2	2 36	2 1	2 54	1 5
W.	2	10 23	11 7	10 41	12 6	3 12	1 6	3 30	1 0
Th.	3	10 59	11 10	11 18	12 8	3 47	0 9	4 2	0 8
F.	4	11 37	12 0	11 57	12 8	4 19	0 4	4 38	0 6
S.	5	—	—	0 18	12 1	4 58	0 3	5 18	0 6
S.	6	0 38	12 5	0 59	12 0	5 38	0 2	5 58	0 9
M.	7	1 20	12 3	1 42	12 0	6 18	0 4	6 39	1 2
Tu.	8	2 4	11 10	2 28	11 10	7 1	0 9	7 24	1 9
W.	9	2 53	11 6	3 21	11 7	7 48	1 3	8 18	2 4
Th.	10	3 49	11 3	4 17	11 5	8 49	1 9	9 25	2 9
F.	11	4 48	10 8	5 19	11 3	10 3	2 4	10 41	3 1
S.	12	5 52	10 4	6 25	11 5	11 19	2 4	11 59	2 9
S.	13	6 58	10 9	7 30	11 10	—	—	0 32	2 1
M.	14	8 2	11 4	8 34	12 3	1 2	2 4	1 28	1 8
Tu.	15	9 4	11 9	9 33	12 8	1 53	1 6	2 18	1 2
W.	16	9 59	12 2	10 25	12 10	2 43	0 11	3 7	0 9
Th.	17	10 50	12 4	11 14	12 10	3 31	0 4	3 55	0 4
F.	18	11 37	12 5	Mid.	12 9	4 19	0 0	4 42	0 4
S.	19	—	—	0 23	12 3	5 4	0 1	5 25	0 6
S.	20	0 46	12 4	1 8	12 0	5 46	0 1	6 7	0 11
M.	21	1 29	11 11	1 49	11 10	6 27	0 6	6 47	1 5
Tu.	22	2 9	11 6	2 30	11 6	7 7	1 0	7 27	2 2
W.	23	2 50	11 1	3 11	11 3	7 47	1 6	8 7	2 9
Th.	24	3 32	10 10	3 53	10 11	8 30	2 1	8 56	3 2
F.	25	4 14	10 4	4 38	10 8	9 23	2 7	9 53	3 8
S.	26	5 4	9 10	5 31	10 6	10 23	3 1	10 56	3 10
S.	27	6 0	9 8	6 29	10 7	11 30	3 1	—	—
M.	28	6 58	9 10	7 28	11 0	0 4	3 7	0 33	3 0
Tu.	29	7 58	10 2	8 28	11 4	1 2	3 3	1 27	2 8
W.	30	8 56	10 8	9 24	11 8	1 51	2 7	2 14	2 3

TIDE TABLES FOR SEPTEMBER, 1909.

PORTSMOUTH (*H. M. Dockyard*).

Week Day.	Month Day.	High Water. Morning. Time. H. M.	High Water. Morning. Height. F. I.	High Water. Afternoon. Time. H. M.	High Water. Afternoon. Height. F. I.	Low Water. Morning. Time. H. M.	Low Water. Morning. Height. F. I.	Low Water. Afternoon. Time. H. M.	Low Water. Afternoon. Height. F. I.
W.	1	—	—	0 17	13 8	4 58	*0 11	5 19	*0 6
Th.	2	0 39	13 8	1 1	13 10	5 40	*1 5	6 0	*0 10
F.	3	1 22	13 7	1 43	13 8	6 21	*1 1	6 42	*0 7
S.	4	2 4	13 3	2 26	13 3	7 3	*0 6	7 24	0 1
𝔖.	5	2 48	12 7	3 10	12 7	7 45	0 5	8 6	1 0
M.	6	3 32	11 9	3 54	11 8	8 29	1 6	8 58	2 0
Tu.	7	4 20	10 10	4 48	10 8	9 32	2 7	10 7	3 1
W.	8	5 22	9 11	6 4	10 0	10 47	3 6	11 35	3 6
Th.	9	6 51	9 10	7 35	10 2	—	—	0 25	3 8
F.	10	8 18	10 3	8 59	10 7	1 8	3 4	1 44	3 4
S.	11	9 31	10 11	9 58	11 1	2 17	2 7	2 44	2 8
𝔖.	12	10 22	11 7	10 41	11 8	3 7	1 9	3 29	1 11
M.	13	10 59	12 2	11 17	12 0	3 47	0 10	4 5	1 3
Tu.	14	11 33	12 6	11 48	12 4	4 22	0 3	4 39	0 9
W.	15	—	—	0 4	12 9	4 53	*0 1	5 7	0 6
Th.	16	0 20	12 6	0 35	12 8	5 21	*0 3	5 36	0 4
F.	17	0 51	12 5	1 6	12 6	5 50	*0 1	6 5	0 5
S.	18	1 20	12 4	1 35	12 5	6 19	0 2	6 33	0 9
𝔖.	19	1 49	11 11	2 3	12 2	6 47	0 8	7 1	1 2
M.	20	2 19	11 6	2 35	11 8	7 15	1 4	7 30	1 10
Tu.	21	2 51	11 1	3 10	11 2	7 47	2 0	8 7	2 5
W.	22	3 30	10 8	3 53	10 6	8 31	2 10	9 2	3 2
Th.	23	4 19	9 11	4 53	9 9	9 35	3 8	10 15	3 10
F.	24	5 34	9 7	6 18	9 8	11 0	3 11	11 52	3 8
S.	25	7 5	10 0	7 51	10 4	—	—	0 40	3 9
𝔖.	26	8 32	10 11	9 7	11 4	1 20	2 11	1 53	2 9
M.	27	9 38	12 0	10 2	12 3	2 22	1 8	2 47	1 7
Tu.	28	10 25	13 0	10 47	13 1	3 9	0 5	3 31	0 6
W.	29	11 8	13 8	11 29	13 9	3 52	*0 9	4 13	*0 7
Th.	30	11 51	14 2	—	—	4 34	*1 3	4 54	*1 1

* Below zero, or datum to which soundings on charts are reduced.

part of the shore included between the high and low water marks is known as the *foreshore.*

But if the observer is not content with these general observations, and takes notice of the times at which high tide occurs on several successive days, he will be struck with the fact that the time of high tide on any one day is nearly an hour later than on the immediately preceding day. The average disparity is about forty-eight minutes. Thus, if it is high water anywhere, say, at London Bridge or Liverpool, at 6 o'clock to-night, it will be high water at approximately 6.48 p.m. to-morrow. At some places the

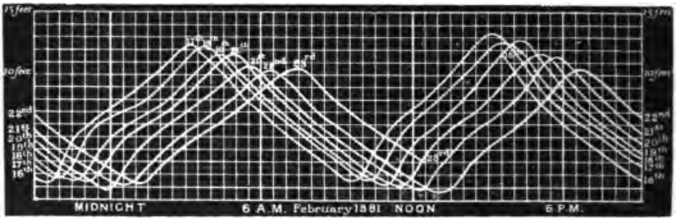


FIG. 157.—Weekly Sheet of Curves traced by a Tide Gauge. The curves show the periodic rise and fall of the height of the water, and also that there are two tides a day. The times of high and low water are shown to occur later day by day, and the heights of successive high and low water are seen to change daily.

rise and fall of the water are recorded by means of a tide gauge. The accompanying diagram (Fig. 157) shows the record of a tide gauge at the Queen's Dock, Glasgow, for seven successive days.

The moon, too, gets about 48 minutes later every day, *i.e.* she crosses the meridian, or souths, about 48 minutes later every day. The interval between two successive passages of the moon across the meridian is what is called a lunar day, and in this period there are always two high tides.

These constant coincidences suggest a connection between the moon and the tides. There is one of an intimate kind, the nature of which will be now explained.

Connection between the moon and the tides.—Coastguardsmen and others have observed repeatedly that when the shadow of a flagstaff or similar object thrown by moonlight has a certain direction, it is high tide; or, what is the same thing, when it is

high tide, the shadow of a fixed object thrown by moonlight always has a particular direction. At London Bridge high water occurs about two hours after the moon has crossed the meridian; so that if the moon is shining and has southed, high water is not far off. We are not always able to see the moon even at night on account of clouds, but the times at which the moon crosses the meridian of London are calculated and tabulated. At Ipswich, high water occurs when the moon is almost exactly due south; at London Bridge, when she is nearly south-west; and at Bristol, when she is E.S.E.

It is plain that there is a connection between the time of high water and the time of the moon's passage across the meridian. The interval between the time at which the moon crosses the meridian of a place and high water at that place is roughly constant, but it differs in amount for different places. The interval between the time of high water and the immediately preceding meridian passage is known as the **establishment of a port**, or, since the moon souths about midday on the day of new moon, the establishment of a port may also be defined as the time of high water at any place on the day of new moon. The following table shows this interval for a few ports in the British Isles.

ESTABLISHMENT OF PORTS.

	H.	M.		H.	M.
Harwich	0	6	Bristol	7	13
Aberdeen	1	0	Rathlin Island	7	56
London Bridge	1	58	Yarmouth Roads	9	15
Whitby	3	45	Holyhead	10	11
Shannon Mouth	4	0	Pentland Firth	11	0
Falmouth	4	57	Dublin	11	12
Swansea Bay	6	10	North Foreland	11	45

The establishments have been selected to show that the interval between the time of high water and the meridian passage of the moon may vary from nothing to 12 hours. But the tide interval between any two places is approximately constant; hence, if the time of high water at any place on a particular day be known, the time at any other place can be determined.

Tides in the ocean and in inland seas. Range of tides.—The difference in the height of the water at high and low tides in the open sea is not more than about two or three feet. A few observations only have been made, but these were obtained at oceanic islands. Tides in the Mediterranean sea are so small—only about

three or four inches—that usually they cannot be recognised, being obliterated by the effects of wind and other disturbing causes. Similarly, tides in the great North American lakes, in the Caspian and other inland seas are nearly imperceptible. In shallow water, or in a converging gulf, this difference in height, or, as it is commonly called, **the range of the tides**, is increased.

Tidal rivers.—If the channel of a tidal river is of uniform width from its mouth landwards, that is, if its width contracts but slowly, the range of the tide decreases on account of friction. In the Thames, for example (Fig. 91), the mean range at Sheerness is about twenty feet, at London Bridge about fifteen, and at Kew Bridge seven feet.

On the other hand, where a river contracts rapidly, the tidal range increases from the mouth towards its source. Thus, at the entrance of the Bristol Channel the total rise at the highest tides is about eighteen feet, at Swansea about thirty, and at Chepstow about fifty feet. This high wave is known as a **bore** (p. 153).

How the moon causes tides.—Newton formulated a law which states that *every body in nature attracts every other body with a force which is directly proportional to the product of their masses, and inversely proportional to the square of the distance between their centres of gravity; and the direction of the force is in the line joining the centres of gravity of the bodies.* It is this **law of gravitation** that explains how the tides are caused. The force of gravity acts between the moon and the earth. The earth attracts the moon and the moon attracts the earth. The earth includes two parts with different physical properties; these are the solid land and the waters of the ocean. The solid part of the earth can move only as a whole, but the ocean waters can move independently. In other words, while water is easily capable of assuming a new shape, the land is not.

Suppose the earth at rest and completely covered by an ocean (Fig. 158). Since the waters on the right side of the earth in the diagram are nearer to the moon than is the centre of the earth (at which point the whole mass of the solid earth acts), it is apparent that the attraction of the moon on these waters will be greater than upon the centre of the earth. Moreover, as the particles of water move over one another easily, the waters in question are pulled up into a heap.

Similarly, the centre of the earth is nearer to the moon than

are the waters on the left of the diagram, and the pulling force is greater, the result being that the earth is pulled away from these waters. The water would thus, in the circumstances, be piled up under the moon and also on the opposite side of the earth, and be depressed as a necessary result at right angles to this, that is, at the places marked "low-water" in Fig. 158. Such is a general explanation of what is known as the equilibrium theory of the tides.

Were the earth at rest, or only slowly rotating, as well as completely covered with water, the lunar tides would, if there were no friction between the water and the surface of the solid earth, be dragged continually round the earth by the moon's attraction. High tide would occur consequently on any given part of the earth when the moon was on the meridian of that

Fig. 158.—The tide-raising action of the moon.

place. But owing to the existence of disturbing causes the tides occur neither directly under the moon nor at the anti-meridian passage, but at intervals after the moon's meridian passage, and hence we get the establishment of ports.

Differential nature of the attraction exerted by the moon and sun.—Referring again to Fig. 158, the student must understand that it is not the attraction of the moon for the earth and the waters covering it as a whole which causes the tidal wave. The tide-generating cause is found in the *difference* between the attraction upon the nearer waters and that upon the centre of the earth, on one hand; and the *difference* between the greater attraction upon the centre of the earth and that upon the more distant waters, on the other.

Spring and neap tides.—If the student has understood the way in which the moon causes the tidal wave, he will have thought that as the relative positions of the sun and earth are at various seasons analogous with those of the moon and the earth, the sun, too, ought to produce tides. This is the case. Were there no

moon, the effect of the sun's attraction would be felt in the formation of a tide wave, which, however, would not be nearly so pronounced as the one caused by the moon. The *differential*

FIG. 159.—Condition for spring tides.

attraction in the case of the moon is more marked than in the case of the sun, and the tide-producing effect of the moon is about two and a half times as great as that of the sun. This follows from the law of gravitation (p. 264). For although the sun's mass is so much greater than the moon's, its distance from the earth is also very much greater than the moon's; and therefore the difference of its attraction upon the earth's surface and at the centre is less than in the case of the moon.

There are thus four sets of tides:

Lunar Tide.	Solar Tide.
Anti-lunar Tide.	Anti-solar Tide.

FIG. 160.—Condition for neap tides.

The expression anti-tide is used to signify the tide on the side of the earth away from the sun and moon. When the solar tides coincide with the lunar tides, so that the effects are superimposed,

we have *Spring Tides* (Fig. 159). When the crests of the two tidal waves are as far apart as possible we get *Neap Tides* (Fig. 160).

The height of high water and the fall of low water are not always the same. Shortly after new and full moon high water is higher and low water lower than usual. These constitute what we have referred to as **Spring Tides.** "These highest tides take place on the west coast of Ireland and on the south coast of England, three transits after the new and full moon, unless diverted by gales of wind or other extraordinary causes. Along the east coast of England they take place four transits after the new and full moon. In the river Thames they occur five transits after the same epochs. These differences arise from the fact, that the same tide wave which produces high water on the west coast of Ireland takes half a day in its progress thence to the east coast of England, and a whole day before it arrives in the river Thames"* (*Admiralty Tide Tables for the British and Irish Ports*).

On the days following the first and last quarters, the difference between the heights of high and low water is little more than half as much as at Spring Tides. These tides, where the range is unusually small, are the **Neap Tides.** These monthly variations are due to the combination of the attractions of the moon and sun upon the waters of the ocean. At the time of Spring Tides, the tide-raising forces of the moon and sun act together, while at Neap Tides they are opposed.

Other variations.—The range of heights of the tides varies with the positions of the sun and moon with reference to the earth's equator, as well as with the distances of these bodies from the earth. The range is greatest when the sun and moon are nearest the earth and nearest to the plane of the earth's equator. These "highest" tides occur when the moon is in perigee (nearest the earth) and near the equator, that is, at the equinoxes, in March and September. The least range occurs at the solstices, in June and December, when the sun is farthest away from the equator, and the moon is at its greatest distance from the earth, that is, in apogee, at the same time. The former are the *equinoctial tides*, and the latter the *solstitial tides*.

Around the British Islands the two tides in a day reach practically the same height at any particular place, but in many parts of the world one tide is much higher than the other.

Co-tidal lines.—The tidal wave does not travel across the ocean with its theoretical velocity. The varying depths of the water, the friction with the bottom, and other disturbing causes make this impossible. But though its velocity alters from place to place,

* See Fig. 162.

the time of high tide will be exactly the same at many stations. If we join on a map all such places where high tide occurs at the same time, we shall cover the map with **co-tidal lines**, which are *lines showing contemporary tides*. The maps of the co-tidal lines of the world (Fig. 161) and of the British Isles (Fig. 162) show the form which these lines take. Suppose a parent wave to start at 12 o'clock noon in the middle of the South Pacific. It reaches New Zealand and Kamtchatka about eight hours later, combines with a wave in the Indian Ocean, and arrives off South Africa at noon on the following day. Here it combines with the lunar tide raised in the Atlantic, and twelve hours later the wave reaches North America. At about 4 o'clock on the morning of the second day the wave arrives at the British Isles.

Courses of tidal waves round the British Islands.—At 5 o'clock in the morning, on the days of new and full moon, the tidal wave which has come up the Atlantic has simultaneously reached the entrance to St. George's Channel in the south and the entrance to the Irish Sea from the North Sea in the north, having been broken into two waves by the Irish coast. The remainder of the journey can be followed from Fig. 162. The two waves approach each other, finally to meet and blend in the middle of the Irish Sea. The part of the course still remaining has thus been described:

"The velocity of the waves being thus checked, the blended waters are diffused over the flat areas of Morecambe Bay, Solway Firth, and the entrances to the Ribble and Mersey, and there they conspire with the rivers in producing the vast sand banks peculiar to these localities. The same waves also bring high water to the east coast of Ireland. The waters, on leaving, again betake themselves to the entrances of the channels from which they started, and there help to build up another advancing wave, which goes through the same circuit, and so on continually. But all this while the main body of the tide wave has proceeded onwards towards the Arctic regions, the portions we have considered being merely its margins. In like manner, also, the English Channel has been traversed by another branch of the same derivative tide wave, which meets at or near the Straits of Dover another tide wave which has circulated round the north of Scotland and down the North Sea, having started from the main body of the tide in the Atlantic at a period twelve hours earlier." *

When it is high water at the entrances of the Irish Sea, it is low water in the middle of that sea, and *vice versa*. Hence the level of the waters oscillates with a kind of sea-saw motion, and at the

* *An Elementary Treatise on the Tides.* By James Pearson.

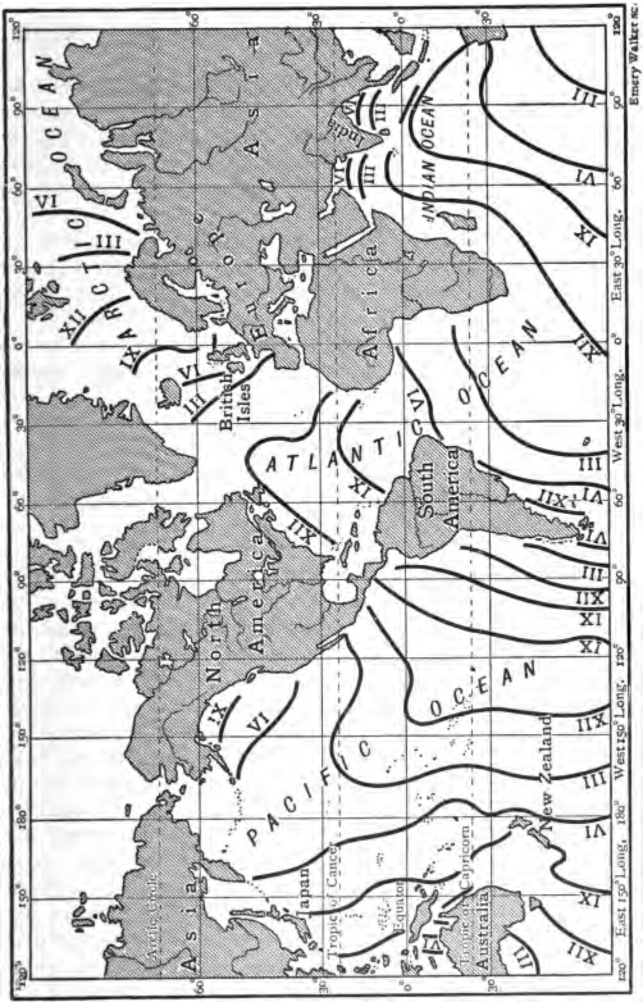


FIG. 161.—Co-tidal lines of the world.

middle of the sea-saw which crosses St. George's Channel opposite Courtown there is little rise or fall of the tide. This line is called a **nodal line** or **hinge** of the tide. There is another nodal line north of Belfast. Similarly nodal lines occur in the North Sea and in the English Channel.

"Over a considerable length of coast **between Portland and Selsea Bill** a double tide is experienced; the first high water occurring more or less in consonance with the progression of the tide from the west, the second with an apparently counter tidal undulation from the eastward, the result being that near the eastern limit of this section a prolonged rise of tide is caused, which, in the Solent, develops into **two distinct high waters** with an interval of from one to two hours between them, and this interval increases progressively along the shore westward of the Needles to three or four hours, until, as Weymouth is approached, the double tide corresponding more closely with the time of low water becomes in fact a **double low water**, and is locally known as the 'gulder.'" (*Admiralty Tide Tables.*)

The nature of tide waves.—When we speak of the motion of a tidal wave, it must not be imagined that the mass of water of which the wave is composed has this motion. The particles of water only *vibrate* at right angles to the direction in which the wave is travelling. A ship, for instance, floating upon the open sea is not carried forward by the progressive waves, but simply rises and falls as they advance and retire.

Tidal streams.—The *vertical* movement of the waters, of which tide-*waves* consist, must be distinguished clearly from that **horizontal** movement of the surface waters, constituting tidal **streams**, to which in shallow waters the tides give rise. Such tidal streams tend to sweep along with them ships and other floating objects, and are therefore a source of danger in navigation near the shore. For example, the true stream in the southern part of the North Sea will always carry a vessel towards the North Foreland while the water is rising at Dover, and from it while it is falling at that place. Examination of Figs. 155 and 156 shows that the directions of tidal streams depend on local circumstances entirely, since at the same moment neighbouring streams may be running in diverse directions. Their directions change, however, with perfect regularity as the passage of the tidal wave causes low water to be succeeded by high, and high water in its turn by low. It is therefore possible to predict with certainty the "set" or direction of the tidal stream at any place for each hour of the tide. Armed with the Admiralty charts of tidal streams—from which Figs. 155 and 156 are copied —the mariner in home waters, knowing his position and able to refer

FIG. 162.—Co-tidal lines of the British Isles.

to tables for the state of the tide at Dover, can turn at once to the particular chart which shows the currents affecting his vessel at the time. More detailed information respecting the direction and rate of the streams is given in the Official *Tide Tables* issued each year by the Admiralty.

EXERCISES ON CHAPTER XI.

1. Spring tides at Liverpool rise to a height of about 26 feet, at Bristol to 33 feet, at Greenock to 10 feet, and at Dublin to 14 feet. When high tide occurs at noon at Dublin, there is high tide at Liverpool at 12.22 p.m., at Bristol at 8.30 p.m., and at Greenock at 1.18 p.m. Explain why the times and the heights of the tides at these places are so different. (C.S.)

2. How are the tides produced? What is the difference between spring tides and neap tides, and how is this difference caused? (C.S.)

3. Describe the principal ocean currents of the North Atlantic and their effects on the climate of Western Europe and Eastern North America. (C.J.)

4. Describe the extent and course of the ocean current commonly known as the Gulf Stream. State why it is so named, whether the reason is in accordance with fact, and if not, how it is at variance with fact. (C.J.)

5. Describe briefly the passage of the tidal wave round the British Coasts, and explain the conditions which prevail (*a*) at Southampton, (*b*) in the Thames Estuary, (*c*) in the Pentland Firth. (O.H.L.)

6. Write a brief account of the importance of the tides in southern and south-eastern England, and describe the character of the tides of the Thames Estuary and of Southampton Water. (L.J.S.)

7. How are the tides caused? Describe the tidal phenomena off the east coast of England and in the Irish Sea. (L.M.)

8. Explain generally how tides are formed, and why some are higher than others. Draw an outline map of Great Britain, and insert the co-tidal lines. (C.P.)

9. On January 1 high water occurred at the following places at the times stated: London Bridge, 3.20 a.m.; Bristol, 8.43 a.m.; Dublin, 12.14 a.m.; Liverpool, 12.35 a.m.; Greenock, 1.31 a.m.; Leith, 3.52 a.m.; Hull, 7.53 a.m. Explain why, in places so near one another, there should be such great differences in the time of high water. (C.S.)

10. What is meant by (*a*) spring tides, (*b*) neap tides? Under what circumstances do neap tides occur? (L.J.S.)

11. Explain the course of the tidal wave around the British Isles. Explain any peculiarities in the tides of different parts of the British coasts. (L.M.)

12. It is customary nowadays to say that the Gulf Stream does *not* reach the British Isles. Explain, as accurately as you can, what is meant by "the Gulf Stream." Give the reasons for its existence and for its comparatively high temperature. Indicate its climatic effects (direct and indirect) and its influence on navigation. Illustrate your answer by a sketch-map. (Cert.)

13. On first coming to Britain the Roman soldiers were astonished at the tides. A Latin author, Tacitus, says of Great Britain, "the tide does not flow and ebb merely as far as the shore, but streams and winds deep inland among ridges and mountains, as though it were its own realm." How do you explain this paragraph? Why should the tides of Great Britain fill the people of Rome with surprise? (Prel. Cert.)

14. What is meant by high tide, low tide, and foreshore? Why do the height of the tide and the extent of the foreshore vary at different places? (C.J.)

15. What changes would be observed in the hour and the height of high tide, if the observations were continued at a place for one month? State briefly the cause of each difference that would be noticed. (J.B.M.)

16. What is meant by spring tides and neap tides, and when do they occur?

PART III.

CLIMATE.

CHAPTER XII.

TEMPERATURE IN RELATION TO CLIMATE.

30. THE COMPARISON OF TEMPERATURES.

1. Heat and temperature.—Heat a quart of water in a suitable vessel until the water feels neither warmer nor cooler than your hand, and notice *how long* it takes to heat the water to this extent. Now heat half a pint of similar water in the same vessel with the same burner or lamp burning at the same rate and at the same distance from the vessel, and notice how long the water must be heated to make it as warm as your hand. Has the quart or the half pint received more heat from the burner? Which is hotter?

Which is hotter, a teaspoonful of boiling water or a gallon of lukewarm water? Which contains more heat? Does the hotness or coolness of a body depend entirely on the amount of heat it contains?

The state of hotness or coolness of a body is called its *temperature.*

2. Mercury as a temperature indicator.—(*a*) Examine an ordinary laboratory thermometer. What is the liquid inside it? Put it in water and heat the water to boiling. At what point on the scale is the top of the mercury column then? Notice whether its position alters as the boiling is continued. Do you think that boiling water gets any hotter as the boiling is continued? Give reasons for your answer.

Put the thermometer in oil, or melted tallow, and heat the vessel containing it. Does the mercury in the thermometer rise higher when immersed in the oil than it did in boiling water. Do you think boiling oil has a higher or a lower temperature than boiling water? Give reasons for your answer.

Put the bulb of the thermometer in water in a beaker and surround the beaker by a mixture of salt and pounded ice. Stir the water with the thermometer and notice and describe the alteration in the level of the mercury column. What is its position on the scale when the water begins to freeze? Does the freezing water get any colder as the freezing continues?

Take the thermometer out of the beaker and plunge it into the surrounding mixture of ice and salt. What is the scale reading now?

Is the instrument you have used a Centigrade (marked "C" or "Cent.") or a Fahrenheit (marked "F" or "Fahr.") thermometer?

3. Comparison of thermometer scales.—(*a*) Compare a Centigrade and a Fahrenheit thermometer. On the former the boiling point of water is marked 100° and the freezing point of water 0°; while on the latter these two temperatures are marked 212° and 32° respectively.

4. Maximum and minimum thermometers.—Examine maximum and minimum thermometers. Experiment with them by alternately warming (by contact with the hand) and cooling (by blowing) the bulb. Notice in each case how the index is affected, how the instrument is "set," and whether it is used in a horizontal or a vertical position. Make a drawing showing the nature and position of the index. What limits of temperature are respectively indicated by the thermometers? Are the scales Fahrenheit or Centigrade?

Heat and temperature.—Temperature may be described in very general terms as the degree of hotness of a body. We may take two different quantities of water and expose them for equal times to the same source of heat. It is common experience that the smaller amount of water is made warmer thereby than the larger quantity. An amount of heat which would raise the temperature of a teaspoonful of water to the boiling point would scarcely make a quart of water appreciably warmer. The temperature of the boiling water is said to be higher then than that of the cooler water, though the *amount of heat* it contains may be very much smaller. If a body at a high temperature and one at a low temperature are brought into contact, there is a passage of heat from the former to the latter until they are both at the same temperature. Hence, we can also define temperature as a condition of bodies that determines which of two bodies when placed in contact will part with heat to the other.

Evidently temperature is analogous to the level of water, for if two cisterns containing water at different levels be put in connection, there will be a flow of water from that in which the water stands at the higher level to the other until the water in both cisterns assumes the same level.

The indication of temperature. The thermometer.—The change of size which bodies experience when heated can be made to provide a method of indicating the change of temperature which bodies undergo. If some form of matter which expands regularly as it is heated can be found, the increase in volume which results can be taken as an indication of the change of temperature. Thus, if mercury in a tube rises through a certain distance for a certain change of temperature, this rise of the level of the mercury in the tube can be looked upon as an equivalent of a certain change of temperature; and it may be argued that if, as the result of its contact with any other body, the mercury rises again to this extent, then the body with which it is in contact has caused it to experience an equivalent change of temperature, and that the body is at the temperature represented by the higher level of the mercury. An arrangement of this kind is called a **thermometer.**

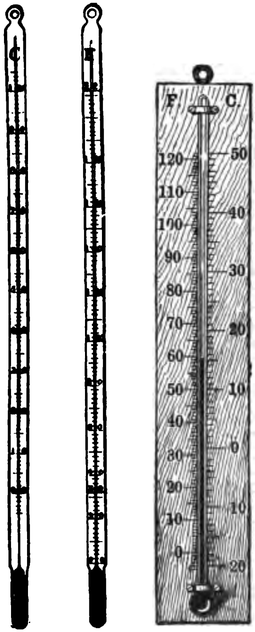


FIG. 163.—Common forms of thermometer.

Two kinds of thermometer scales are in common use (Fig. 163). One is known as the **Centigrade** scale, and the other as the **Fahrenheit** scale. When a thermometer is placed in melting ice, the mercury in it remains at the same level so long as any ice is unmelted. This level of the mercury marks what is called the **Freezing Point,** because at this temperature water freezes. The freezing point is marked 0° (read "no degrees") on a Centigrade thermometer, and 32° on a Fahrenheit thermometer. A thermometer

placed in the steam from water boiling at sea level records the same temperature so long as the water continues to boil. The level at which the mercury stands is called the **Boiling Point,** because at this temperature water begins to boil. The boiling point is marked 100° on the Centigrade thermometer and 212° on the Fahrenheit thermometer. It is thus seen that a degree on the Centigrade thermometer represents a greater difference of temperature than a degree on the Fahrenheit thermometer. Hence, in speaking of the temperature of the air at a place, for example, we must be careful always to state with what kind of thermometer the temperature was measured. Degrees on a Centigrade thermometer are always written with C. after them, thus, 0° C. and 100° C.; while degrees on the Fahrenheit thermometer are followed by F., thus, 32° F. and 212° F.

FIG. 164.—Hypsometric apparatus.

The hypsometer.—As will be explained in a later chapter, the pressure of the atmosphere becomes less with an increase of altitude. Now the temperature at which water boils depends upon the pressure of the atmosphere; the greater the pressure of the air above the boiling water, the higher the temperature of boiling. When we say that the temperature of boiling water is 100° C. or 212° F., it is understood that the water is boiling at sea level. Water boils at temperatures lower than 100° C. at places above sea level, the higher the altitude the lower being the temperature of boiling. These facts are made use of by explorers to determine the heights of mountains above sea level. Having determined the temperature at which water boils at the place of observation, it is possible by calculation, after reference to tables, to find out the height of the place above sea level. Such tables are included in *Hints to Travellers*, published by the Royal Geographical Society (8th edition, vol. i., pp. 209 to 214). An examination

of Fig. 164 will show how the apparatus for determining the boiling point at a given place is used.

Maximum and minimum thermometers.—It is often desirable to know the highest temperature reached since a thermometer was last read. For example, in weather reports it is usual to record the highest temperature reached during the day, and it is manifestly impracticable to watch the thermometer continuously with a view of determining this. By a simple device the thermometer itself can be made to record this reading. The arrangement by which this is accomplished constitutes a **maximum thermometer** (Fig. 165). In one kind of instrument there is introduced into the stem of the thermometer (before sealing it), above the mercury, a thin piece of iron wire which works loosely in the tube. When the mercury expands it pushes this piece of wire before it and on

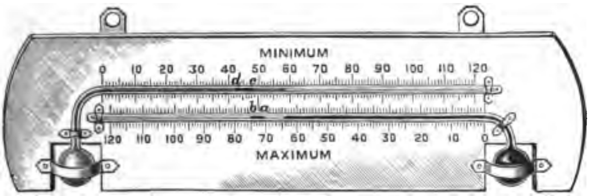


FIG. 165.—Maximum and minimum thermometers.

contracting leaves the wire at the highest place to which it has been pushed. The reading indicated by that end of the wire nearest to the mercury is the maximum temperature which has been reached. To set the thermometer again the piece of wire is drawn back to the mercury by the attraction of a magnet which hangs near the thermometer for this purpose. This is only one of many devices which have been suggested and used for this purpose; the student should refer to one of the larger books on heat or meteorology for an account of the others.

Similar arrangements have been devised for measuring the lowest temperature reached during the night or any other period. They are known as **minimum thermometers.** For measuring low temperatures it is general to use alcohol thermometers, and these can be made themselves to register the lowest temperature experienced. Into the stem of the thermometer a marker is introduced as with maximum thermometers, but the marker is of a different kind. It is either a fine capillary tube or a black index, shaped like a dumb-bell. When the temperature falls the alcohol contracts, and the marker is dragged back with the liquid in consequence of the adhesion between the two materials. When the

temperature rises again, the index remains stationary, the alcohol flowing round or through it according to the kind of marker, but not causing it to undergo any displacement. The end of the marker farthest away from the bulb will indicate the lowest temperature which has been reached.

The mean of the maximum and minimum temperatures of any one day is referred to shortly as the **mean temperature**. The average of such mean temperatures during any given period is called the **average mean temperature** for that period.

31. CONDITIONS AFFECTING VARIATIONS OF TEMPERATURE.

1. **Varying intensity of heat received from sun.**—The angle at which the sun's rays strike any place on the earth varies, because

(*a*) the earth rotates on its axis,

(*b*) the earth's axis is inclined to the plane of its orbit, and

(*c*) the latitudes of places differ.

Which of the above reasons respectively give some explanation of the following facts?—(i) In January the average mean temperature of Tasmania (lat. 42° S.) is 60° F., while that of New York (lat. 42° N.) is 32° F.;

(ii) In July the average mean temperature of London (lat. 51° N.) is 64° F., while that of the Falkland Islands (lat. 51° S.) is 36° F.;

(iii) the temperature of a place is usually higher at midday than at sunset, although at sunset the place may have been exposed to several hours' more sunshine than at midday;

(iv) it is always hotter in Madagascar than in the Kanin Peninsula (N. Russia) on the same meridian. Give reasons for each of your answers.

Which would you expect to be warmer—an English hillside sloping to the south, or a neighbouring piece of flat ground? Would the same difference be found in New Zealand?

2. **Proximity or otherwise to the ocean.**—(*a*) Weigh out ½ lb. of dry gravel; put it in an air oven (Fig. 166) or a water oven, and keep the oven at the temperature of boiling water (p. 278) for half an hour. Have ready ½ lb. (8 fluid ounces) of boiling water, and also two beakers containing convenient equal quantities of cold water at any, the same, temperature. Pour the half pound of boiling water into one beaker of cold water, and the half pound of hot gravel into the other. Stir each mixture and read the temperature with a thermometer. Which mixture attains the higher temperature? Which must have given out the greater amount of heat in cooling—the half pound of boiling water or the half pound of gravel at the same temperature? Will warm water or warm land at the same temperature be likely

to give out more heat in cooling from summer to winter? Will a seaside or an inland place on the same latitude (other conditions being equal) be likely to have milder winters? Why?

(*b*) In one beaker place $\frac{1}{2}$ lb. of gravel, and in another $\frac{1}{2}$ lb. of water at the same temperature. To each add the same quantity of boiling water, and mix. Which mixture reaches the higher temperature? Is water or gravel warmed less by the same amount of heat? Is a seaside or an inland place on the same latitude (other conditions being equal) likely to be hotter in summer? Why?

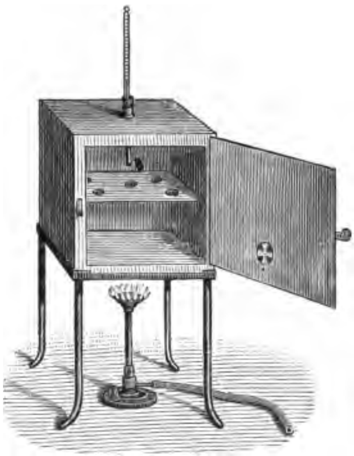


FIG. 166.—An air oven.

Are seaside or inland places, on the same latitude, likely to have the greater difference between their summer and winter temperatures? Why?

Why is water said to have a *high capacity for heat*?

(*c*) Give some explanation of the following facts.—

(i) In January the average mean temperature of Vancouver Island is 36° F., while that of Winnipeg, on the same latitude, is 0° F.;

(ii) In January the average mean temperature of Mafeking is 90° F., while that of the west coast of Africa, on the same latitude, is 70° F.;

(iii) In July the coast of North California has an average mean temperature of 60° F., while Colorado, on the same latitude, has one of 90° F.;

(iv) the difference between the summer and winter temperatures of Verkhoyansk in Siberia is 116° F., while the range in the Lofoten Islands, on the same latitude, is 23° F.

(*d*) *Temperature of surface waters.*—Judging from the paths of the ocean currents (Fig. 154) alone, which of each pair of the following coasts do you suppose has the warmer surface waters *on the Tropic of Capricorn*: (i) East Africa or West Africa, (ii) West Africa or Brazil, (iii) Brazil or Chile, (iv) Chile or Queensland? Give reasons for your answers.

What is the difference in the latitudes of New York and the Shetland Isles? How do you account for the fact that the mean annual temperature *of the ocean surface* at both places is the same (50° F.)? What two currents are chiefly concerned? Where does each originate?

3. Presence of water vapour in the atmosphere.—Observe whether very cold days and nights of winter occur when the air is dry and the sky clear, or when the air is damp and the stars are hidden at night by clouds. Water vapour in the air is said to prevent the heat of the earth from escaping into space, as the glass of a greenhouse or "cold frame" prevents the heat inside from escaping. Observe the temperatures inside and outside greenhouses and "cold frames" at various times, and try to find out if the glass really acts in this manner. Why is a glass screen sometimes used in rooms to protect people from the direct heat of the fire?

4. Influence of rainfall.—(*a*) Notice whether the temperature in *winter* changes to any marked extent when rainy weather comes on. If so, does it rise or fall? Make similar observations in *summer*; is there any obvious connection between temperature and wet weather in summer?

(*b*) Comment on the following temperature and rainfall records * at Llandudno in January and July:

Date.	Temperature.		Mean Temperature.	Rainfall.
	Max.	Min.		
Jan., 1908.	° F.	° F.	° F.	Inches.
3rd -	33	26	29·5	—
4th -	34	22	28	—
5th -	39	24	31·5	—
6th -	51	37	44	0·05
7th -	49	40	44·5	0·31
8th -	42	39	40·5	0·04
9th -	40	36	38	—
10th -	37	28	32·5	—
11th -	39	34	36·5	—
12th -	42	29	35·5	—
July, 1908.				
6th -	63	55	59	—
7th -	62	52	57	—
8th -	63	51	57	0·22
9th -	65	53	59	0·01
10th -	65	54	59·5	—
11th -	63	52	57·5	0·42
13th -	65	51	58	—
14th -	66	54	60	0·01

How is the mean temperature for any day obtained?

* From the *Daily Weather Reports* of the Meteorological Office.

Varying intensity of the heat received from the sun.—Some of the waves of heat, light, and other forms of energy travelling through space from the sun—which together constitute sunshine—come into contact with the earth's atmosphere. A small part of them is reflected by the upper layers of the atmosphere, but the greater number enter, and either are transmitted to the earth or are absorbed in their passage through the air. About one-half of the rays which enter the atmosphere, and are capable of being converted into heat energy, are absorbed in their passage, while the rest are transmitted, and, reaching the surface of the earth, are absorbed by it and warm it. The angle at which the

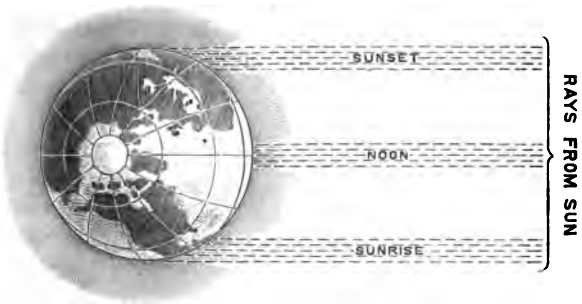


FIG. 167.—Showing the greater thickness of atmosphere passed through by the rays of the sun at sunrise and sunset than at noon.

sun's rays strike any given region of the earth determines their heating effect to a very great extent.

The **diurnal variation** of temperature at any given place may be explained in this manner. At sunrise and sunset the rays have to pass through a greater thickness of atmosphere than at noon, consequently more of their heat is absorbed by the air (Fig. 167). Moreover, the same bundle of noonday rays is also spread over larger surfaces at sunrise and sunset. Naturally, such a diurnal variation is least at the poles, where the sun shines continuously, or is below the horizon continuously, for six months. The difference between day and night temperatures is greater and greater as the poles are left behind, and reaches a maximum at the Equator.

The broad **differences between summer and winter temperatures** in any particular latitude are to be accounted for by the inclination

of the earth's axis to the plane of the ecliptic (p. 93). As a result of this, the sun's rays strike the earth in London at an angle of 15° on Dec. 21, and at an angle of 62° on the longest day (Fig. 58). In other words, "on Dec. 21 a given surface in London receives 25·9 per cent., and on June 21, 88·3 per cent. of the heat it would receive if the sun were overhead." The minimum temperature is reached about Jan. 8–11; the maximum about July 14–16.

Again, the altitude of the sun varies in **different latitudes** (p. 94). The more nearly vertically the rays from the sun strike the earth, the less will be the extent of atmosphere traversed, and the larger will be the amount of heat radiation which reaches a given area of the earth during the day. The sun is most nearly vertical in equatorial regions, and it is there, in general, that most heat will be received, the amount getting smaller as the poles are approached (Fig. 168).

On the other hand, Fig. 168 also shows that, at midsummer, within the Arctic circle (lat. 66½° N.), the amount of heat received from the sun is greatest **nearest** the pole. The explanation is that the increased **length of the day** (p. 96) more than compensates for the greater weakness of the sunshine, which is caused by the obliquity of its rays.

A little thought will show that varying latitude must have precisely opposite effects upon *seasonal* variation and *diurnal* variation of temperature. Seasonal variation is least in equatorial regions —where the amount of solar heat received differs but little in summer and winter—and is greatest at the poles (Fig. 168).

How the atmosphere is warmed.—Besides the heating of the atmosphere by those of the sun's rays which it directly intercepts, the air becomes warmed, firstly, by *contact* with the heated earth, and, secondly—since the earth continually radiates its own heat— the air becomes heated also by radiations from the earth. The heat-rays which leave the earth in this second process are found to have undergone a complete change of character; they are no longer luminous, but belong entirely to the kind of radiation called *dark-heat waves*. The atmosphere cannot transmit them as it could before, for, while the air is transparent to the luminous rays from the sun, it is more or less opaque to the dark radiations from the

earth. A similar change in heat rays from the sun is brought about in a more marked degree by glass, a fact which is made use of in the construction of greenhouses.

Tyndall showed that air with aqueous vapour in it is nearly one hundred times more absorptive of dark heat rays than pure dry air. In speaking on this point, he said in one of his lectures: "No doubt can exist of the extraordinary opacity of this substance to the rays of obscure heat; *particularly such rays as are emitted by the earth after being warmed by the sun.* Aqueous vapour is a

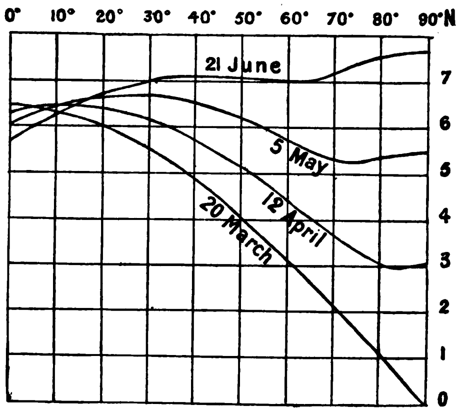


Fig. 168.—Relative amount of solar heat received at each latitude at various periods. (After Wiener.)

blanket more necessary to the vegetable life of England than clothing is to man. Remove for a single summer night the aqueous vapour from the air which overspreads this country, and you would assuredly destroy every plant capable of being destroyed by a freezing temperature. The warmth of our fields and gardens would pour itself unrequited into space, and the sun would rise upon an island held fast in the iron grip of frost."

Some of the consequences, both direct and indirect, of the absorptive influence of this aqueous vapour are of the greatest interest. Among the direct consequences, those which result from an absence of water vapour in the air, as described in the above quotation, may be included. A realisation of such conditions occurs on the moon, where there is no water envelope to prevent

the radiation of heat, and consequently there the difference between the highest temperature of the lunar day and the lowest temperature of the lunar night must be immensely great.

An approximation to this condition of things occurs at various places on the earth's surface. The winters of Tibet, for instance, are, from the scarcity of water vapour in the air and consequent excessive radiation, exceedingly severe. Over the desert of Sahara, too, the air is exceedingly dry, and the days are intensely hot, followed by exceedingly cold nights. After sunset, since there is so little water vapour to prevent a free radiation of heat, the temperature of the earth rapidly falls, often reaching the freezing point. The same thing is true of the central parts of Australia.

Vertical distribution of temperature.—It should now be clear why the air nearest to the earth is warmest, and why it is that as we ascend into the atmosphere the air becomes colder. This decrease of temperature with increase of altitude is spoken of as the **vertical distribution of temperature.** "Perhaps the most remarkable phenomenon revealed by the investigation of the upper air with balloons carrying self-recording instruments is the comparatively *sudden cessation of the fall of temperature at a height varying with the time and latitude.* Above this height, which may be regarded as the height of an irregular but roughly horizontal surface dividing the atmosphere into two regions, the temperature [about $-70°$ F.] at any time varies little in a vertical direction, showing on the average a tendency to increase. This comparative absence of regular vertical variation of temperature in the upper region led to the name 'isothermal layer or region' to distinguish it from the lower atmosphere, in which the vertical variation of temperature is about 6° C. per 1000 metres.* . . . The actual cessation of the fall of temperature was first noticed by M. L. Teisserenc de Bort in June, 1899, and again in March, 1902. . . . Teisserenc de Bort found the average height at which the change occurred to be about 11 kilometres." †

Although **the average fall of temperature up to a height of about 7 miles is thus 1° F. for 304 feet,** the rate of decrease is not the same throughout. Gold showed that the rate up to 2 kilometres (1¼

* *I.e.* 1° F. in 304 feet.

† *I.e.* about 7 miles. *British Association Report,* Winnipeg, 1909: "The Present State of our Knowledge of the Upper Atmosphere." By Messrs. E. Gold and W. A. Harwood.

miles) depended very considerably on the wind direction as well as on the time of the year, and results obtained from kite ascents have given the rate up to 3 kilometres as about 1° F. for 388 feet.

It has been found repeatedly, however, that the mean temperature of the air in contact with a mountain is slightly below that at the same height in the free atmosphere. The elevated parts of the earth's surface are not so well protected—by the "blanket of aqueous vapour"—against loss of heat as are the more low-lying regions, and the chilled surface of the mountain naturally affects the temperature of the air in contact with it.

It is common knowledge that in hot countries like India climate is modified by height above the sea level. In that country it is customary for Europeans to retire to places on the hills during the hot seasons, because of the more bearable conditions experienced there.

It is also interesting to note that the same gradations in the character of the vegetation remarked in travelling from the equator to the poles are also to be observed in ascending a high mountain in the tropics. In the valley a profusion of tropical plants abounds, while at the snow-capped summit the only evidences of vegetation to be discovered are specimens of Arctic (or "Alpine") plants such as are found in the polar regions, while the intermediate journey is through a region which can be divided into zones of vegetation precisely similar to those of middle latitudes (Chapter XVI.).

Temperature modified by proximity to the ocean.—Countless experiments, essentially of the nature of Expt. **31**, 2, (*a*) and (*b*), but made with all the refinements necessary to avoid error, have proved that water requires more heat than any other substance to raise its temperature through a given range; and, on the other hand, that in cooling from one given temperature to another, water gives out more heat than any other substance. This is expressed concisely by saying that water has a greater capacity for heat, or has a greater **specific heat**, than any other substance. As a consequence the same exposure to the sunshine does not make the water of the ocean so warm as the neighbouring land in summer; and, conversely, an equal loss of heat in the winter does not cool the ocean, and the air overlying it, so much as it cools the neighbouring land and the air just above the land. The high specific

heat of water, therefore, is instrumental in bringing about a marked **uniformity in the climates of islands.** Surrounded as they are by water, they experience a small annual range of temperature only (Fig. 176), which in the case of some islands in the tropics amount to no more than four or five degrees. A small range of temperatures is one of the characteristics of an **oceanic climate.** Though the uniformity in the case of larger islands in temperate zones is not so pronounced, it is still considerable compared with the difference

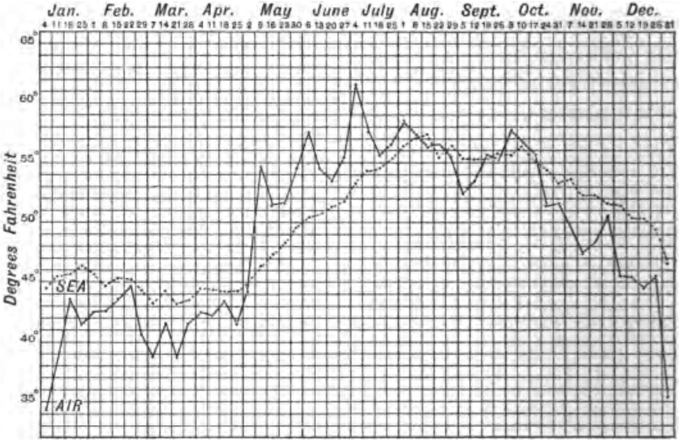


FIG. 169.—Weekly average temperature of the sea, and of the air over the land, at 9 a.m. at the Biological Station, Port Erin, during 1908. The curves show how the temperature of the sea lags behind that of the air, being higher in winter and lower in the height of summer. (From the 23rd Annual Report of the Liverpool Marine Biology Committee.)

between the extreme winter and summer temperatures of places far removed from the coast of the nearest ocean. Places of this character, like Great Britain or Tasmania, are said to have an **insular climate,** while inland stations like Moscow experience what is called a **continental climate.** Verkhoyansk in Siberia and the Lofoten Islands are both situated in the same latitude; but while the annual range in the latter place is only 23° F., in the former it is as much as 116° F. Nearly as pronounced a difference is noticed by comparing Bergen in Norway with Yakutsk in Siberia, which differ in position as regards their latitude by only two

degrees; yet Bergen has an annual range of but 22° F. as compared with one of 111° F. at Yakutsk. A fuller classification of climates is given in Chapter XV.

Distribution of ocean temperature.—The temperature of the ocean water at various depths is determined by using a self-

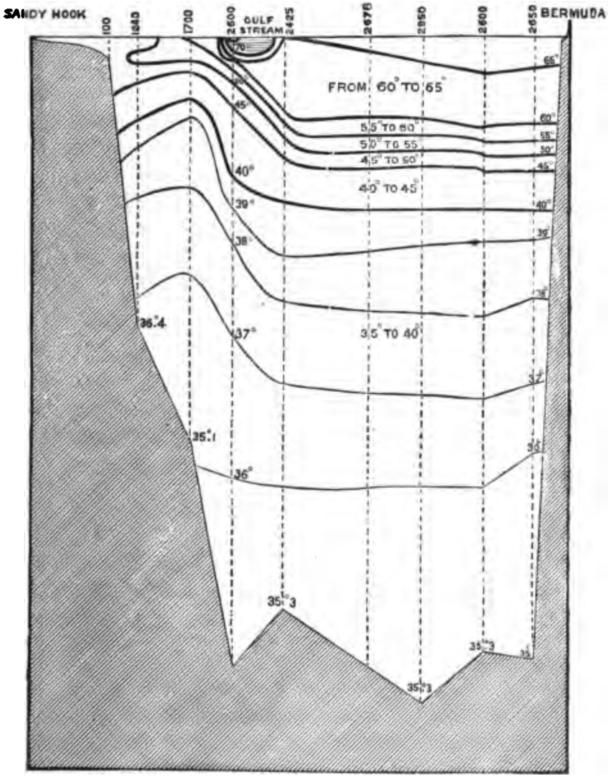


FIG. 170.—Section of the Atlantic Ocean between Sandy Hook (New York) and Bermuda. Dotted lines show depths; the others are lines of equal temperature.

registering thermometer, constructed to bear the immense pressure it is subjected to when sunk. It will be sufficient here to enumerate simply the chief results of the work of various expeditions, such as that of the *Challenger*. The **temperature**

of the surface waters of the ocean varies fairly regularly with the latitude and the time of the year (Fig. 169).* It is greatest in the tropics, where it sometimes reaches a temperature of 86° F., as at places a little north of the equator; but, speaking generally, it can be said to vary from 60° to 80° F. The temperature falls as the poles are approached, until a temperature slightly below the freezing point of pure water has been reached well within the Arctic Circle.

Although the temperature of the surface waters thus varies, in a general sense, with the latitude, it is affected naturally by *ocean currents*, since many streams and drifts distribute warm tropical waters northward and southward, and certain other currents carry cold Arctic and Antarctic waters to regions of middle latitudes. The Gulf Stream drift and the Labrador current (p. 252) are, for example, responsible respectively for the fact that the average *ocean* surface temperature is the same (50° F.) at New York (lat. 41° 6′ N.) and the Shetland Isles (lat. 60° 30′ N.); and similar, though less marked, departures from the general rule are noticeable in other parts of the world.

The difference between the highest summer temperature and the lowest winter temperature of the surface water is greatest in the temperate zones, where it is as much as 10° F., while this difference is least near the equator and poles. The daily variation of temperature is insignificant, rarely being more than 1° F. It is least about sunrise, and reaches a maximum about 4 p.m. This constancy in the temperature results chiefly from two familiar properties of water, (*a*) its high specific heat (p. 287) and (*b*) its slight power of conducting heat. As a consequence of its high specific heat, water requires a large amount of heat in order to warm it, but once having its temperature raised, it cools again with a corresponding difficulty.

The poor conducting power of water explains what has been noticed everywhere throughout the oceans, viz. that the heat from the surface water does not spread throughout its mass. A glance at Fig. 170 will show that the **temperature of the water at a comparatively small depth** is very much lower than at the surface. At a depth of a little over half a mile, a temperature of 40° F. is reached, and the temperature gets very little lower from this depth to the bottom, for the lowest reading of the thermometer in Fig. 170 at a depth of 2,650 fathoms is 35° F. The same fact is brought out in the following table:

* The mean temperature—for the current month—of the seas surrounding the British Isles is indicated on the *Daily Weather Report* by a scale of tints.

THE MEAN TEMPERATURES FOR ALL THE OCEANS AT DIFFERENT LEVELS.

Depth in fathoms.	Temperature °F.	Depth in fathoms.	Temperature °F.
100	60·7	900	36·8
200	50·1	1000	36·5
300	44·7	1100	36·1
400	41·8	1200	35·8
500	40·1	1300	35·6
600	39·0	1400	35·4
700	38·1	1500	35·3
800	37·3	2200	35·2

Other conditions affecting temperature.—The range of temperature is influenced directly by the **prevailing winds** (Chapter XIV.). For instance, the winds which blow for the greater part of the year in the Sahara, coming from the higher latitudes of Europe, are felt as cold, dry winds, and do much toward lowering the temperature of this desert. Or, taking the case of our own islands, the west and south-westerly winds, arriving after a journey over the Atlantic Ocean, where they have become warmed and saturated with moisture, are powerful agents in causing a mild climate on the west coast of this country; whereas, the easterly and north-easterly winds coming from the continent of Europe are colder and drier, and bring about harsher and more bracing conditions.

Indirectly also, the *winter* temperatures of the British Isles are dependent to a remarkable extent on the prevailing west and south-westerly winds, because these winds are laden with so much moisture which is thrown down as **rain.** When rain falls on a cold day the temperature rises (p. 282). The reason for this will be explained in Chapter XIII. Heat is liberated always when rain is formed; but the resulting rise of temperature is naturally less noticeable on an already warm summer day than in winter, and may indeed be quite neutralised by the cooling which accompanies rapid evaporation from the wet, warm ground. The consequence is that in winter our most rainy districts are in general the warmest (Figs. 171 and 214). In summer the broad distribution of British temperatures has no obvious relationship to the rainfall, in spite of the fact that the prevailing winds are still south-westerly (Fig. 212), and that the rainfall is greater in summer than in winter (Fig. 211).

The temperature of a district is influenced also by such causes as **the slope of the ground**; should the inclination be in the direction of the midday sun the amount of warming experienced will be greater than in those cases where the slope is towards the rising or setting sun.

The influence of oceanic currents is also often instrumental in producing variations of climate. The winter climate of countries on the west of Europe is made milder by the warming effect of the North Atlantic water and the winds blowing from it; while cold currents, if the winds blow over them towards the land, result in a contrary effect. The east coast of North America is but little cooled by the Labrador current (Chapter XI.), because the winds over it blow off-shore.

Cultivation results often in modifications of climate. The clearing of forest land, which up to a certain point is productive of an increase of temperature and a beneficial diminution of the moisture, may, if carried too far, lead to increased evaporation, and therefore loss of moisture, and thus seriously diminish the productiveness of a country. The extensive draining of a marshy district has been known in several instances to result in an increase of its mean annual temperature. It is alleged, for instance, that one of the results of the drainage which has been effected in Great Britain during the past century has been an increase of one or two degrees in its mean annual temperature.

32. ISOTHERMS.

1. The meaning of the word isotherm.—At 8 a.m., Jan. 14, 1908, each of the following towns had a temperature of 40° F.: Fraserburgh, Ballater, Crieff, Glasgow, Newton-Stewart, Ramsey, Conway, Welshpool, Worcester, Oxford, London, Maidstone and Dungeness.

Mark these places on an outline map of the British Isles and connect them by a smoothly curved line. The line is the isotherm of 40° F. for the hour in question. Define the term *isotherm*.

2. To draw the July isotherms.—The following are the average mean July temperatures * of the places named. Mark each place on an outline map of the British Isles, with its temperature, and then join with a smoothly curved line all places having the same temperature.

56° F.: Coll, Canna, Portree (Skye), Poolewe, Wick.

57° F.: Port-Ellen (Islay), Tarbert, Oban, Loch Quoich, Cromarty, Fraserburgh.

* *I.e.* the average of the mean daily temperatures (p. 296) of the place during July.

58° F.: Erris Head, Burtonport, Moville, Larne, Portpatrick, Ayr, Gourock, Crianlarich, Huntly, Stonehaven.

59° F.: Aran Islands, Ballinrobe, Sligo, Strabane, Antrim, Downpatrick, Whitehaven, Gretna, Morpeth, Tynemouth.

60° F.: Youghal, Ennis, Athenry, Cavan, Dublin, Wicklow, Tenby, Cardigan, Bangor, Barrow, Appleby, Northallerton, Hornsea.

61° F.: Lundy Island, Worms Head, Chester, Doncaster, Yarmouth.

62° F.: Canterbury, Portsmouth, Exeter, Launceston, Watchet, Cardiff, Builth, Radnor, Derby, Nottingham, Boston, Orfordness.

63° F.: Cambridge, Bishop Stortford, Gravesend, Horsham, Marlborough, Oxford, Bedford, Cambridge.

Compare the map with Fig. 172.

Estimate from these isotherms the probable average mean July temperatures of Inverness, Perth, Dumfries, Galway, Newcastle, Lancaster, Crewe, Northampton and Southampton.

3. To draw the January isotherms.—In a recent examination each candidate was provided with an outline map of the British Isles, on which the following towns were marked by dots and numbered with their mean January temperatures (° F.) as given below. Candidates were asked to draw upon the map the isotherms for 38°, 40° and 42° F., and to explain the course which they take.

	° F.		° F.
Kirkwall (Orkney Is.)	39·3	Moville	39·8
Cape Wrath	39·1	Bundoran	42·2
Thurso	38·7	Enniskillen	40·0
Butt of Lewis (Hebrides)	40·3	Belfast	39·7
Stornoway	39·2	Donaghadee	40·4
Monach Is.	41·8	Athlone	38·5
Portree (Skye)	39·1	Dublin	41·1
Inverness	38·2	Foynes	41·1
Fort-Augustus	38·3	Limerick	40·0
Fort-William	39·0	Valentia I.	44·8
Oban	40·8	Cork	41·3
Peterhead	38·0	Waterford	41·3
Aberdeen	37·6		
Arbroath	37·6	Silloth	38·5
Perth	37·3	Newcastle	38·6
St. Andrews	38·2	Douglas	41·2
Edinburgh	38·2	Barrow	39·0
Skerryvore Lighthouse	42·1	Scarborough	37·7
Rhinns Point (Islay)	41·9	Holyhead	42·0
Rothesay	38·8	Conway	41·2
Dumbarton	38·4	Liverpool	39·8
Girvan	40·6	Leeds	37·8
		Hull	37·8
Malin Head	40·5	Lincoln	37·4

	°F.		°F.
Aberystwith	41·2	Taunton	40·0
Leicester	37·8	Exeter	41·3
Cromer	37·3	Falmouth	43·7
Pembroke	42·6	Plymouth	43·6
Carmarthen	39·6	Ventnor	40·3
Cardiff	40·0	Portsmouth	39·4
Cheltenham	39·6	Brighton	40·0
Colchester	37·5	Dungeness	40·1
London	37·9	Dover	39·8
Ilfracombe	42·3		

Mark the places and temperatures on an outline map, and draw the isotherms in the manner explained for contour lines on p. 29. First put in the 40° F. isotherm which roughly follows the west coast of Scotland and England, noticing that it must pass between the Butt of Lewis and Stornoway, between Fort-William and Oban, between Islay and Rothesay, etc., at a distance proportional to the differences between their temperatures and 40° F.

In Ireland the 40° F. isotherm is a separate *closed* curve. Observe also that the 38° F. isotherm consists of *two* curves (one enclosing the eastern counties of Scotland and the other the eastern counties of England) which are not connected on the map.

Compare the map when finished with Fig. 171.

4. Study of isotherm maps of the British Isles.—(*a*) *Summer isotherms.*—To which of the factors modifying temperature (considered in Sec. **31**) are the following facts shown on Fig. 172 respectively to be attributed?—

(i) The general direction of the isotherms is from west to east; in other words, the temperature decreases from south to north.

(ii) The isotherms bend to the north as they cross the land, and dip to the south as they cross the sea; in other words, the summer temperature along any latitude is lower over the sea than over the land.

(iii) The highest temperature is found in the London district, the isotherms of 63° F. and 62° F. forming more or less concentric curves round it.

Which *inland* part of *southern* England is least likely to be affected by the prevailing (westerly and south-westerly) winds?

(*b*) *Winter isotherms.*—Study Fig. 171, and refer also to Fig. 214.

(i) How does the direction of the 40° F. isotherm in Great Britain agree with the direction of a *generalised* line separating districts of more than 40 inches of mean annual rainfall (p. 328) from those of less? How do you account for the facts?

(ii) Is a similar correspondence to be noticed in Ireland? Try to explain why the isotherm of 40° F. in Ireland is a closed curve.

(iii) Why have the winter isotherms of the British Isles a general north and south direction?

(iv) What general succession of temperatures might be expected in a journey in January along lat. 52° N. from Valentia to Harwich? What is the direction of ***most rapid*** decrease of temperature * from Valentia? What changes of temperature might be expected in January in a journey from London to Fort-William *via* Rugby, Manchester, Carlisle and Glasgow?

(v) Try to account for the shape and position of the 38° F. January isotherm in England.

(vi) Why do the isotherms crossing the Irish Sea dip to the north in winter and to the south in summer?

(*c*) *Mean annual isotherms.*—How would you determine the mean annual temperature of a place? Study Fig. 173. To what extent do the mean annual isotherms combine the features of the mean January and July isotherms? What evidences does the map show of the influence of prevailing winds?

5. Study of isotherm maps of the world.—(*a*) *Summer and winter isotherms.*—Examine Figs. 174 and 175.

(i) Find in each case the area in which the average mean temperature is above 80° F. Describe the distribution of this area in January; is it chiefly north or south of the equator? Why? Describe its distribution in July; is it chiefly north or south of the equator? Why?

(ii) Where do the hottest regions extend furthest from the equator in July? Why?

(iii) Where do the coldest regions approach the equator most nearly in January? Why?

(iv) Trace round the earth on both maps the isotherms which pass through the British Isles. Where and when do they depart most from an east and west direction? Does Fig. 195 suggest any explanation of this?

(*b*) *Mean annual isotherms.*—Study Fig. 177.

(i) Are the areas of more than 80° F. chiefly on land or over the ocean? Why?

(ii) In what part of the world is the mean annual temperature gradient between 60° F. and 10° F. greatest? Why? In what part of the world is the mean annual temperature gradient between 60° F. and 10° F. least? Why?

(iii) Is there more land within the Arctic or the Antarctic circle? In which is the mean annual temperature higher? Why?

* Sometimes called the "line of temperature gradient."

Isotherms.—If we draw lines on a map through those places which have the same corrected* lower air temperature at any given time, we are able to form an idea of the *horizontal* distribution of temperature, that is, the distribution of temperature of the air at the earth's surface at the time. Such lines are called "lines of equal temperature," isothermal lines, or **isotherms.**

Fig. 171.—Mean January isotherms of the British Isles.

Isothermal surfaces.—A **surface** connecting all points having the same temperature is called an *isothermal surface*. Plainly the isothermal surface of 40° F. will cut the sea level along the isothermal *line* of 40° F., but it will rise above the surface of those parts of the earth which are warmer than 40° F. (p. 286), and will be below the surface of those parts which have a surface temperature below 40° F.

Isotherms may evidently be drawn to show the horizontal distribution of temperatures at any given hour, or the horizontal distribution of the mean (*i.e.* the mean of minimum and maximum) temperature for any given day, or of the average of such mean daily temperatures for any given month, or year, or number of years. In regions over which the temperature varies considerably between neighbouring places, the isotherms naturally lie closer together than where the temperature is more uniform, just as contour lines on a map lie closest together where the gradient is greatest. Indeed the term **temperature gradient,** suggested by this analogy, is often used to indicate the "rate"

* *I.e.* "reduced to sea level" by allowing for the effect (p. 286) of altitude upon temperature.

(measured, say, in degrees per 100 miles) at which the temperature alters along any given line; and just as the direction of greatest slope (*e.g.* the path of a stream) on inclined ground crosses contour lines at right angles, so the line of greatest temperature gradient crosses isotherms at right angles.

Isotherm maps display in a striking manner the modification of temperature caused by such circumstances as varying season, latitude, proximity to the ocean, direction of prevailing winds, etc., considered in Section **31**. The crust of the earth, moreover, is made up of different materials, with varying specific heats and divers degrees of conducting power, and these are consequently warmed to different extents and the contiguous atmosphere participates in the same variations.

Isotherms of the British Isles.—A comparison of the isotherms of the British Isles for January and July shows very clearly that our **winter** temperatures depend chiefly on the heat liberated in the formation of rain. The temperature gradient has, therefore, the same general direction as have the rain-bearing winds, *i.e.* from south-west to north-east. Comparisons of Figs. 171 and 214 show it to be broadly true that our greatest winter temperatures are found in districts of heaviest rainfall, and *vice versa*. In **summer**, on the other hand, the effect of the varying intensity of the sunshine at different latitudes is not neutralised to any great extent in our islands, either by the rainfall or by other circumstances, so that our summer isotherms run roughly east and west. Local departures from the general directions just mentioned are interesting and suggestive. In winter those isotherms which cross the Irish Sea curve to the north in transit, because the sea is

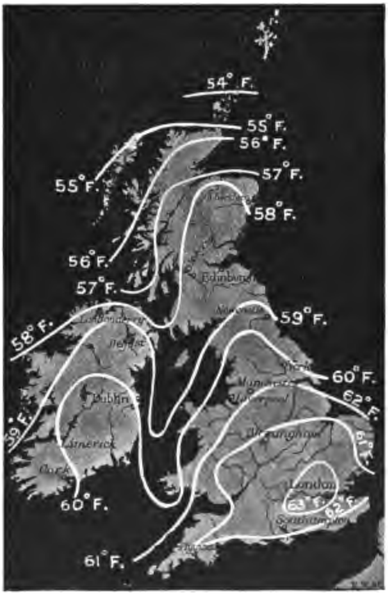


FIG. 172.—Mean July isotherms of the British Isles.

warmer than the land; in summer they curve to the south, because then the sea is cooler than the land; in both cases the facts are caused by the high specific heat of water (p. 287). In the same manner may be explained the northward curve of the summer isotherms over the land. As might have been expected, the highest mean summer temperatures prevail in our islands in the London district, because this is the *inland* part of *southern* England which is least exposed to the cooling effects of the south-westerly summer breezes.

FIG. 173.—Mean annual isotherms for the British Isles. (Buchan.)

Isotherms of the world.—The same principles find an equally instructive application in the study of isotherm maps of the world. In **January** (Fig. 174) the hottest belt of the world lies somewhat to the south of the equator, as a consequence of the inclination of the earth's axis; within this belt the highest temperatures are found naturally on the land masses rather than over the sea. The **heat equator** (the line joining the hottest places on successive meridians) * consequently lies almost entirely to the south of the geographical equator in our winter, dipping most markedly south over South America, Africa and Australasia. The isotherms are broadly parallel to the parallels of latitude. In general, they take the form of wavy lines, which at this time of the year bend to the north as they cross the great oceans, and to the south as they cross the continents. This behaviour, of course, indicates that in the northern hemisphere (where it is winter) the air over the oceans is warmer than that over the land; and that in the southern hemisphere (where it is summer) the air over the oceans is cooler than that over the land. In the N.E. Atlantic the northward

* It should be noted that the heat equator is not an isotherm.

indentation of the winter isotherms is especially marked, as a result of the prevailing south-westerly warm winds. The curious distribution of our British winter temperatures is thus seen to be merely the local expression of a phenomenon affecting the whole of western Europe, and giving rise also to a great difference in the temperatures of the east and west shores of the Atlantic.

The January isotherms are noticeably closer together in the northern hemisphere than in the southern; in other words, the temperature falls off more rapidly towards the north pole than towards the south pole. This is partly because in our winter the north pole is turned away from the sun, and partly because there is more land in the northern hemisphere than in the southern.

In our summer the rays of the sun shine more directly upon the northern than upon the southern hemisphere, and the results are displayed graphically by a map of the July isotherms (Fig. 175). The hottest belt has migrated northward, and the heat equator now lies almost wholly to the north of the geographical equator, making excursions northward as it crosses the great land masses. The northern isotherms are spaced more widely, and curve more or less to the north over the great land masses; the southern isotherms still dip from north-west to south-east on crossing the continents, indicating the relatively low temperature of the west coasts. Crossing the oceans, the July isotherms of the temperate zones run more nearly parallel to the lines of latitude than is the case in January. No sign is now to be seen of the great embayment of the isotherms over the north-east Atlantic, since the prevailing winds here affect the summer temperature much less than the winter.

Range of temperature.—The amount by which the temperature of a place varies throughout the year is a very important factor in determining climate. From Fig. 176, or from a comparison of maps of summer and winter isotherms, it is clear that the Torrid Zone is on the whole a region of moderate annual range of temperature, while the North Temperate Zone has extreme variations as compared with the South Temperate Zone, and the Northern Hemisphere has on the whole greater ranges than the Southern. The reason for this is that water areas vary little in temperature during the year, while land areas change their temperatures much more readily. The effect of great land areas in producing large ranges of temperature is very evident. In Northern Asia there is a range of 120° F.; in northern North America, 80° F.; in Northern Africa, Australia, South Africa, and southern South America, 30° F. Another noteworthy feature is

the small temperature range on the west side of continents in temperate zones.

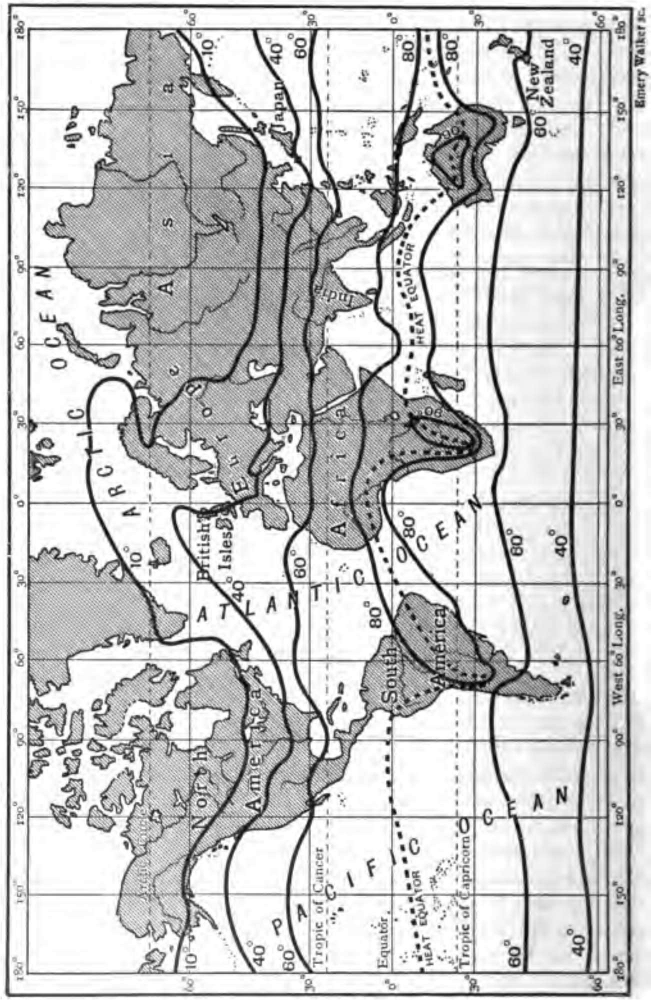


Fig. 174.—Mean January isotherms of the world.

Mean annual isotherms of the world.—An examination of Fig. 177 (as of Fig. 173) shows that the mean annual isothermal lines

follow paths which indicate to a large extent a compromise between the extreme conditions encountered in January and

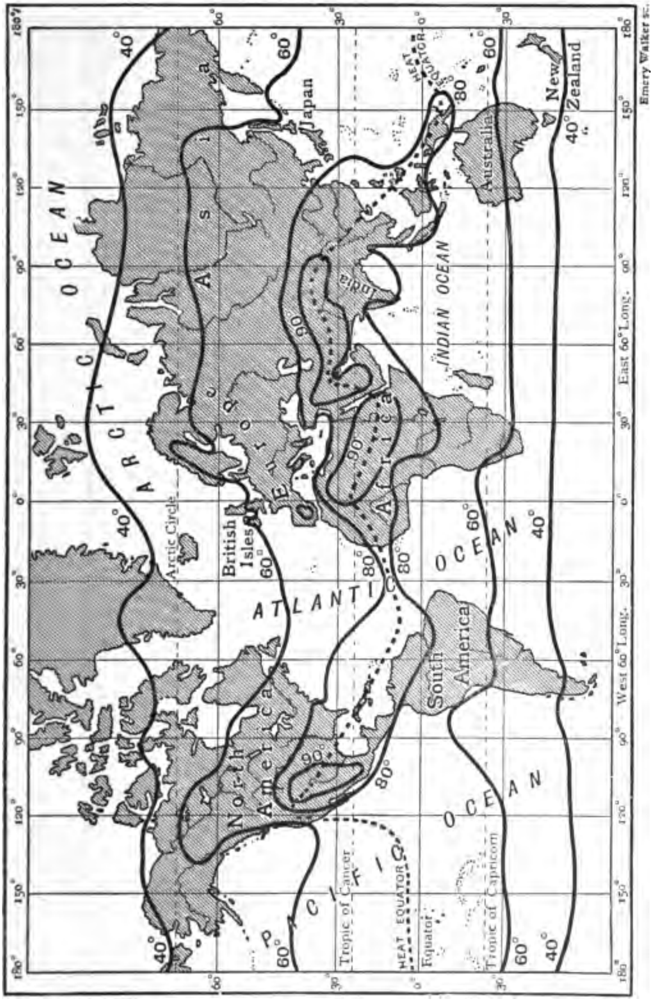


FIG. 175.—Mean July isotherms of the world.

July. Fig. 177 also emphasises general facts which the variation from winter to summer tends to obscure. The map shows, for

example, that the temperature gradient is in general steeper and more irregular over the northern than over the southern continents; so that, even though the mean position of the heat

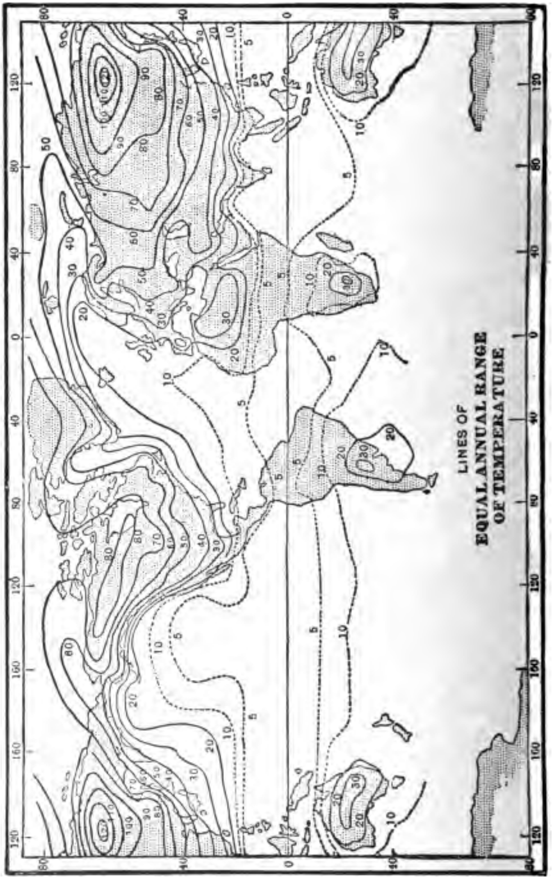


FIG. 176.—Lines of equal annual range of temperature. The numbers appended to the lines indicate the range in degrees Fahrenheit.

equator is somewhat to the north of the geographical equator, certain countries in the north temperate and Arctic zones are decidedly colder, though these zones regarded as a whole are warmer,* than Southern regions of corresponding distance from

* Compare Fig. 93.

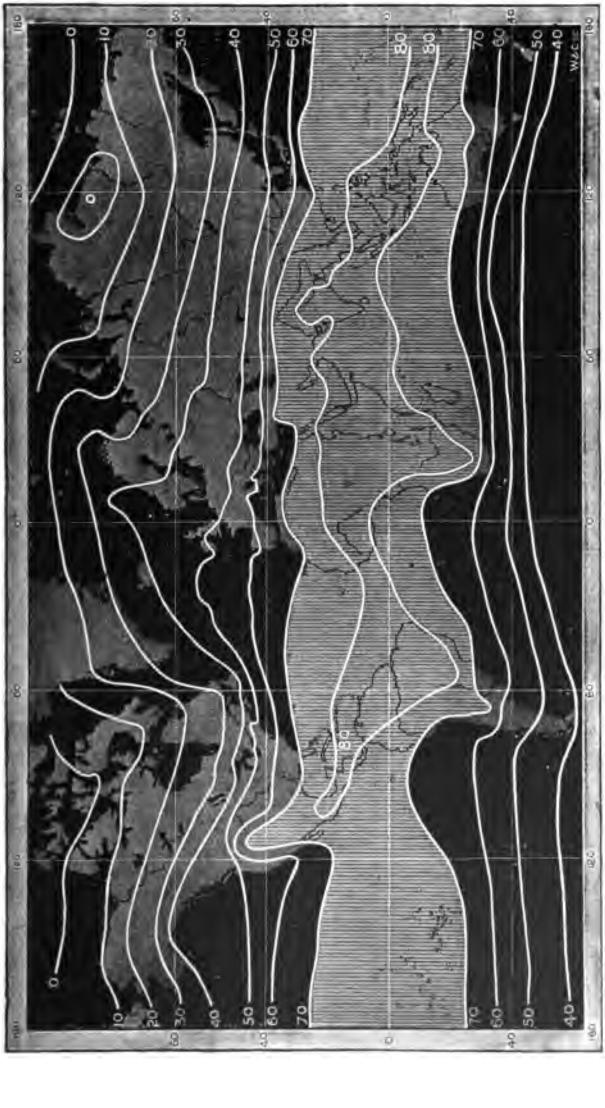


FIG. 177.—Mean annual isotherms for the world. The belt of temperatures above 70° F. is shaded.

the equator. The map shows, too, that the influence of the prevailing winds—as exemplified by the temperatures of the North Atlantic and of the coasts of South America and Africa—is not of merely temporary importance, but has a marked effect upon general climate.

It ought to be mentioned that although the influences affecting temperature-distribution, which have been considered in this chapter, account satisfactorily for the broad facts, the subject is complicated by various other circumstances having a more or less temporary or local significance. Thus, a theory has of late years been put forward that certain disturbances of the atmosphere in one part will produce opposite conditions in another. For instance, an unusually high summer temperature in the Arctic seas will set free a large amount of ice, and the polar current, arriving later at Iceland and the North Sea, lowers the temperature of those regions to an exceptional extent.

EXERCISES ON CHAPTER XII.

1. What is meant by isothermal lines? Why do they vary in their direction at different seasons of the year? Illustrate your answer by a particular example. (C.P.)

2. What part of the British Isles has the highest average temperature (*a*) in January, (*b*) in July? In each case give a reason. (C.S.)

3. What is an isotherm? Show why it does not coincide in direction with a parallel of latitude, and why it varies its position during the year. (C.P.)

4. Describe the average distribution of temperature in Great Britain during the winter months, pointing out how it differs from the distribution during the summer. Account for the facts. (O.H.L.)

5. Temperature is regulated by latitude. Criticise this statement, using well marked climatic regions of Europe for purposes of illustration. (P.T.)

6. On what parts of the coasts of the British Isles would you expect to find (*a*) a mild climate in winter, (*b*) a cool climate in summer? Give reasons for your answers. (C.J.)

7. Describe and explain the use of the maximum and minimum thermometer. At what hours would you expect to find the temperature at its maximum and its minimum respectively? (C.J.)

8. What are the principal causes which affect the temperature of a district?

9. Describe as exactly as you can the direction taken in Europe by the January isotherm of 32° F. What do you understand by this? What might you deduce from this fact alone as to the commercial value of some of the rivers of Europe?

10. From the following data draw on squared paper three curves showing the maximum, minimum and mean temperatures (see Fig. 169).

Date.	Max. Temp.	Min. Temp.
Nov. 1	52° F.	48° F.
„ 2	54°	48°
„ 3	51°	48°
„ 4	53°	47°
„ 5	50°	40°
„ 6	48°	38°
„ 7	47°	36°

11. Draw a curve showing the rise and fall of the thermometer at Liverpool during Nov. 1906 (see Fig. 169).

Nov. 1	47° F.	Nov 11	41° F.	Nov. 21	48° F.
„ 2	48°	„ 12	43°	„ 22	57°
„ 3	37°	„ 13	40°	„ 23	53°
„ 4	40°	„ 14	36°	„ 24	46°
„ 5	46°	„ 15	45°	„ 25	40°
„ 6	37°	„ 16	43°	„ 26	43°
„ 7	48°	„ 17	48°	„ 27	48°
„ 8	47°	„ 18	37°	„ 28	50°
„ 9	46°	„ 19	40°	„ 29	53°
„ 10	40°	„ 20	41°	„ 30	46°

12. What are isothermal lines? Describe how to find isothermal lines for your classroom.

How do you account for the different temperatures in different parts of the room?

13. On a blank map of Europe draw boldly three or four isothermal lines for January; in another colour draw three or four for July. Explain in writing any great difference in their general direction. Give reasons for this difference.

14. Make a comparison of the distribution of the isotherms on the maps of the world. Show January and July isotherms, and explain the movement of the regions of highest temperature throughout the year.

15. The annual range of temperature in tropical Africa is small. Account fully for this. (J.B.M.)

16. Give an account of the ocean currents of the North Atlantic Ocean, and discuss to what extent they influence the climates of adjacent coasts. (J.B.M.)

17. Indicate (if possible showing isothermal lines on a sketch-map) the broad distribution of summer and winter temperatures in Great Britain. (J.B.M.)

18. Describe the changes of temperature encountered in passing from the surface to the bottom of the sea (*a*) in the Atlantic, (*b*) in the Mediterranean. Account for the difference between the two cases. (C.S.)

19. What is the difference between the sea water at the surface and at the bottom of the Atlantic as regards saltness and temperature? Does the Mediterranean differ from the Atlantic in these respects, and if so, how and why? (C.J.)

CHAPTER XIII.

THE FORMS OF WATER.

33. SOME CHANGES PRODUCED IN WATER BY HEAT.

1. Expansion of water on freezing.—Obtain a small, corked bottle with a narrow neck. Fill it with water and cork tightly, driving the cork in as far as possible. Pass strong fine twine several times round the bottle from top to bottom and over the cork, to keep the latter in. If the string is likely to slip, notches in the cork will prevent it. A small piece of wood similarly notched and put at the bottom of the bottle will prevent the string from slipping there. A "screw-top" mineral-water bottle, filled with water and sealed by screwing in the stopper tightly, may be used instead. Place the bottle in a bowl and cover it with a freezing mixture of ice and salt. Carefully cover the bowl with a duster or cloth until you hear the bottle burst, then take off the covering and examine what has happened. Describe and explain the result of your experiment.

If possible, repeat the experiment with a small cast-iron cylinder (Fig. 140), provided with a stopper which screws in. A louder explosion is heard.

You will understand from these experiments why water pipes burst in winter. Why is it that the pipes are not found to be burst until the thaw sets in?

2. Melting point of ice.—Put some small pieces or shavings of clean ice into a beaker and insert a thermometer into them. Record the temperature indicated. Pour in a little water, stir the mixture, and again record the temperature. Place the beaker on a sand-bath and warm it gently. Notice the reading of the thermometer *so long as there is any ice unmelted.* In all these cases the reading of the thermometer is practically the same, indicating that the temperature of melting ice is constant.

3. Heat required to melt ice.—(*a*) Let a few lumps of ice stand in a beaker until some have melted. Notice that the temperature is 0° C. Counterpoise two empty beakers of the same size in the pans of a balance, and put a small lump of ice into one, and the same weight of water from the melted ice in the other. You have thus equal weights of ice and water at 0° C. Pour equal weights of hot water into the two beakers. When the ice is melted, observe the temperature of the water in each beaker. The temperature of the water in the beaker in which the ice was placed will be found much lower than that of the water in the other beaker, because the ice uses up a large quantity of the heat in melting into water.

(*b*) Take equal weights of hot water in two large beakers of the same size. Place a piece of ice in one of the beakers, and observe the temperature of the water when it has melted. Pour ice-cold water into the other beaker until the same temperature is reached. Find, by weighing, the weights of ice and ice-cold water which have been added. It will be found that a small weight of ice has as much cooling effect as a large weight of ice-cold water.

4. Cooling produced by evaporation.—(*a*) Sprinkle a few drops of spirits of wine, or ether, on your hand. Notice that the liquid soon disappears, and its presence in the air can be detected by its odour. The rate at which the liquid evaporates is increased by waving the hand about. The hand feels cold.

FIG. 178.—Flask fitted with tube and water trap for passing steam into water; *S*, *S′* is a screen.

5. Heat liberated when steam is condensed.—(*a*) Put equal quantities of cold water into two beakers of the same size. Observe the temperature. Boil water in a flask with a delivery tube (Fig. 178), and pass the steam into the cold water in one of the beakers. When the temperature of the water has been raised about ten degrees, take away the delivery tube, pull the cork out of the flask, and pour enough boiling water from it into the other beaker to raise

the temperature by the same number of degrees. Find the weights of steam and water added to the cold water in the two beakers. It will be found that a small weight of steam, in condensing into water, produces the same heating effect as a much larger amount of water.

(*b*) Compare in the same way the heating effect of equal weights of steam and boiling water. To do this, pass steam into cold water and, by weighing, determine the amount condensed. Then add, to an equal amount of cold water, a quantity of hot water equal to the quantity of steam condensed.

Water and weather.—The character of the climate of a place depends profoundly upon the behaviour of water under different conditions of temperature. The importance of the high specific heat of water in this relation has been emphasised in Chapter XII., and it is now necessary to consider what changes in the state and density of water are brought about by variations of temperature, and what is the effect of such changes upon the weather.

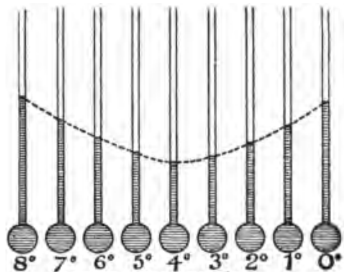


Fig. 179.—Changes in the volume of water between 8° C. and the freezing point.

Changes in volume and density as water is cooled.—If the volume of a body becomes greater whilst the quantity of matter in it remains the same, what is called the **density** of the body must become less and less. It is quite clear that if the same amount of matter occupies a larger space, it must be packed less closely into that space, and it is **the closeness with which matter is packed into a space** which is referred to by the term density. The general effect of a rise of temperature upon bodies is to cause them to expand, and therefore to decrease their density; while a fall of temperature causes them to contract, and therefore increases their density. Water forms an interesting exception to this rule. When water is cooled gradually, the same mass of water becomes smaller and smaller in volume as it is cooled down to 4° C. (Fig. 179). We can express the same fact in another way, and say that its density becomes greater as it is cooled down

to 4° C. From this temperature the volume of the water gets larger as we continue to cool it, and its density therefore becomes less. On the contrary, if we began with water at 0° C. and gradually warmed it, the density would increase steadily up to 4° C., and from that temperature upwards the density would diminish regularly.

Maximum density of water.—Because any mass of water has a smaller volume at 4° C. than at any other temperature, or, what is the same thing, has a greater density at this than at any other temperature, we speak of 4° C. as being the temperature at which water has its **maximum density.**

This may be summed up in the statement that **water at a temperature of 4° C. will expand whether it be heated or cooled.**

Results in nature of the peculiar expansion of water.—From a consideration of the expansion and contraction of water, it is easy to understand what happens when the water of a pond is cooled gradually on a frosty night. As the temperature of the water at the surface becomes lower and lower, the water there becomes smaller and consequently denser. It therefore sinks, and its place is taken by warmer water from below. The same cooling and sinking of the surface water continue until the temperature of the whole of the water is 4° C., at which temperature it has its maximum density, and consequently when the water at the bottom of the pond reaches this temperature it remains where it is. After the temperature of the water at the surface has reached 4° C., any further cooling causes it to expand and become lighter, and this result continues until 0° C. is reached and the water at the surface is changed into ice, which, being considerably lighter than water, remains on the surface. Ice is, moreover, a very bad conductor of heat, and consequently the temperature of the water below the ice gets cooler very slowly, and the thickness of the ice increases at but a small rate.

This condition of things prevents several disastrous consequences which would of necessity follow if ice were denser than water. If ice were denser than water, it would sink to the bottom of the pond at the moment it was formed, and as the frost continued, the ice would spread throughout the water. Not only would this result in the destruction of many water

animals in the pond, but it is probable that the heat of summer would be insufficient to melt it completely.

Expansion of water as it freezes.—When water is cooled to 0° C. and changes into ice, the ice which is formed takes up more room than the water does. In forming ice, the water expands. Large bomb-shells have been filled with water completely, plugged securely, and left out a whole night during very cold weather. In the morning some were found cracked round the middle, with a large belt of ice sticking out through the crack, and from others

FIG. 180.—To illustrate the force of expansion of freezing water.

the plug had been forced out and a rod of ice was found sticking out where the plug had been inserted (Fig. 180).

Not only do we learn from such experiments as these that water expands in forming ice, but also that the force with which the expansion takes place is very great, being strong enough to break a bomb-shell. When water turns into ice, the latter occupies more room than the water from which it was produced; in fact, every 9 cubic inches of water produces about 10 cubic inches of ice. It is because of this expansion of water that we often have water-pipes bursting during frosty nights. The bursting of the pipe takes place when freezing occurs, but is only discovered when the thaw takes place. This has given rise to a belief among some people that thawing causes the pipes to burst, but that is quite wrong.

Change of state.—When a solid body is melted by heat, and is turned thereby into a liquid, or a liquid is changed into a vapour, or when the reverse changes take place, without any alteration in chemical composition, the body is said to undergo a change of state. Thus, if we heat ice it is first liquefied or becomes water; and, on continued heating, it is vaporised or becomes steam.

Temperature of melting.—When a solid is heated, the first effect is usually an increase of size. But if the heating is continued long enough, when the solid reaches a certain temperature, which differs with different solids, melting begins. The solid changes into a liquid. The temperature at which the melting takes place is called the **melting point**.

In general, so long as any of the solid remains unmelted, the temperature does not rise above the melting point. When a Centigrade thermometer is placed in some small pieces of clean ice, the thermometer records a temperature of 0° C. If some of the ice is put into a beaker, and a little water is poured in, the thermometer still records a temperature of 0° C. Even when the beaker, with the ice and water in it, is put over a laboratory burner and heated gently, the thermometer still reads 0° C., so long as there is any ice unmelted. It is evident, then, that the temperature of melting ice is always the same, and remains the same so long as there is any ice unmelted.

Latent heat.—These experiments are of the greatest importance, and should be understood clearly. It is certain that when a mixture of ice and water is heated over a laboratory burner heat is being given to the mixture continually. Yet the temperature as recorded by the thermometer does not rise. The question arises, what becomes of this heat, as it has no effect upon the temperature of the mixture? The ice is melted gradually and, if the heating is continued long enough, is all changed into water. As soon as this has happened, every further addition of heat raises the temperature of the water. These considerations lead to the conclusion that the heat previously given to the mixture is all used up in bringing about the change of ice into water.

This amount of heat which is necessary to change a solid into a liquid is spoken of as *latent heat.*

Latent heat of water.—The amount of heat which is required to change the state of a gram of ice, converting it from the solid to the liquid condition without raising its temperature, would be sufficient to raise the temperature of a gram of water through 80° C., or would raise that of 80 grams of water through 1° C.

Similarly, to melt 1 lb. of ice requires as much heat as is necessary to raise the temperature of a pound of water from 0° C. to 80° C., or as much heat as would raise the temperature of 80 lbs. of water through one degree Centigrade. The fact is often expressed by saying that the latent heat of water—or **the latent heat of fusion of ice—is 80.**

Natural consequences of latent heat of water.—Just as it is necessary, before a pound of ice can be changed into a pound of water, to pour into it an amount of heat which would raise the temperature of a pound of water through 80° C., so before a pound of water can be changed into a pound of ice, precisely the same amount of heat must be taken from it. This is why it needs so many cold nights to cover a pond with ice, for not until every pound of water at the surface has had this large amount of heat taken from it can it change into ice. For just the same reason it requires a large amount of heat to melt completely the snow in the roads and the ice on the ponds, so that the snow and ice do not disappear as soon as a thaw has set in.

Convection.—The process by which water and other liquids are heated must be noticed here. The water nearest the source of heat is heated, expands, and in consequence becomes lighter; it therefore rises through the general mass of the liquid. Something must take its place, and the cold water at the top, being heavier, sinks and occupies the space of the water which rises. This water in its turn gets heated and rises, and more cold water from the surface sinks. This behaviour gives rise to upward currents of heated water and downward currents of cool water, until by-and-by the whole of the water is heated. Such currents are known as **convection currents**, and the process of heating in this manner is called **convection.**

Boiling.—Eventually the water as a whole becomes so hot that the bubbles of vapour which are formed near the source of heat are not condensed again in their upward passage through the liquid, and coming to the surface they escape as steam. The liquid is then said to *boil.* The temperature at which bubbles of this sort are formed throughout the mass of the liquid is quite definite (when the pressure of the atmosphere is the same), and is called the **boiling point.**

Effect of pressure on the boiling point.—A word or two must be said with respect to the reservation which has been made in the last paragraph, and also on p. 278, about the pressure of the

air. The weight of the atmosphere is considerable. It presses upon the surface of every body with a force dependent upon the extent of the air above the body; this force will clearly be less at the top of a mountain, and greater at the bottom of a mine.

If we wish to boil a liquid, therefore, in circumstances where the pressure of the atmosphere is great, we shall have to heat the liquid more, before the bubbles of vapour can escape at the surface, than when the pressure is less. If we heat the liquid more, its temperature will get higher before boiling takes place, and consequently its boiling point will be higher when the pressure is greater. The boiling point of a liquid therefore depends upon the pressure of the atmosphere at the time and place of the experiment.

Heat disappears during vaporisation.—When a liquid is changed into vapour a certain amount of heat is used up. It does not matter whether the liquid evaporates quietly, or boils; every gram of it requires a certain amount of heat before it becomes converted into vapour. In boiling, this heat is supplied by the flame or fire, and in ordinary evaporation it is taken from the objects in contact with the liquid. The faster the evaporation, the more rapidly heat is absorbed in this way. When a liquid evaporates rapidly, the cooling produced is very noticeable. For instance, if a few drops of either spirits of wine, or ether, are sprinkled upon the hand, the liquid soon disappears and the hand feels cold. The heat necessary for the evaporation of these liquids is taken from the hand, consequently the hand becomes cooler and cooler as the vapour is formed.

In tropical countries, where the land becomes *verv hot* during the day, evaporation takes place so rapidly after sunset that the water is sometimes so much cooled as to freeze, by the extraction of the heat required to bring about the change from liquid to vapour. It is readily noticed that not only is the dust laid by watering the roads in summer, but the air is pleasantly cooled by the evaporation of the water.

Latent heat of steam.—When once water in an open vessel has begun to boil, its temperature gets no higher than the boiling point. So long as there is any water left, no matter how much it is heated, its temperature remains the same. All the heat is absorbed, or used up, in bringing about the change from the liquid state to that of vapour. It requires much more heat to convert one gram of water at a temperature of 100° C. into steam at the same tempera-

ture, than it does to change a gram of ice at 0° C. into a gram of water at 0° C. In fact, whereas the heat required to bring about the latter change would raise 80 grams of water through 1° C., the amount of heat necessary to vaporise 1 gram of water would suffice to raise the temperature of no fewer than 536 grams of water through 1° C. This is expressed by saying that the latent heat of steam—or **the latent heat of vaporisation of water—is 536.**

The exact amount of heat which becomes latent when a liquid is converted into a vapour is liberated when the vapour is once more condensed to form a liquid. It is for this reason that a scald from the steam of boiling water is worse than a scald from the boiling water itself, and that the air is warmed by the formation of rain in cold weather (p. 291).

34. WATER VAPOUR IN THE ATMOSPHERE.

1. Presence of water vapour in the air.—(*a*) Weigh a dish containing some dry calcium chloride, and then expose it to the air for some hours. Notice that the substance soon becomes pasty, and after a time dissolves in the water it has absorbed from the air. Find the increase in weight.

(*b*) Expose a small beaker one-third full of oil of vitriol (*i.e.* strong sulphuric acid—*a most corrosive substance*) to the air for several days. Notice that the liquid increases in volume and weight. Why?

(*c*) Do you suppose there is much moisture in the air present in well-stoppered bottles of strong sulphuric acid or of calcium chloride? Why? What method is employed in your school for keeping the air dry inside balance cases?

2. Dew point.—Gradually cool some water in a thin glass tumbler, or beaker, by adding powdered ammonium chloride or nitrate and stirring with a thermometer. Watch the outside of the glass (avoiding breathing upon it), and as soon as it becomes dimmed with moisture, notice the temperature of the contents of the tumbler. This temperature is the *dew point* at the time and place of the experiment. What is the source of the dew? Fan the tumbler vigorously; does the dew persist? Wipe the outside of the tumbler dry, and put it quickly into a balance case in which there is provision for keeping the air dry. Is the dew point the same inside as outside the balance case?

Do you suppose dry air requires more, or less, cooling than moist air at the same temperature before it deposits any of its water vapour as dew?

Find out whether, at any given temperature, the *rate of evaporation* of water varies according to the amount of moisture already present in the air, and if so, how the rate is affected. (Place the same number of drops of water, from a burette, in similar watch-glasses, and notice how soon the water dries up when the watch-glasses are kept in places differing in dryness of air.)

3. Mason's hygrometer.—Take a reading with Mason's hygrometer (the wet and dry bulb thermometer, Fig. 181), just *outside* a balance case in which there is provision for drying the air. Which thermometer shows the lower temperature? Why is the wet bulb cooler than the other? What is the difference between their temperatures? Now put the apparatus *inside* the balance case. Is the temperature of the air the same inside the case as it is outside? Does the temperature of the wet bulb remain the same inside the case as outside? Is the difference between the temperatures of the dry and wet bulbs greater when the instrument is inside, or when it is outside, the case? Why? How could you find out, by using the wet and dry bulb thermometer, which of two rooms, at the same temperature, contained the drier atmosphere? How could you learn, without actually determining the dew point, whether the temperature of the air was near, or far from, the dew point?

4. Dew.—(*Outdoor work.*)—(*a*) Is dew deposited more freely on calm or on windy, on clear or on cloudy, nights?

(*b*) Find the dew point in the open air towards evening. To what temperature will the ground require to be cooled in order that dew may be deposited on it? Leave out a minimum thermometer on the ground, and examine it next morning, as soon after sunrise as possible, to see if this temperature has actually been reached during the night. Has dew been formed? On what objects have you observed dew to be deposited most and least freely respectively?

(*c*) Arrange stones, pieces of slate, and sheets of paper, on grass on a clear, still evening; and next morning examine them as soon after sunrise as possible; observe whether dew is more abundant on their upper or on their lower surfaces. Similarly, experiment with inverted tumblers, earthenware jars, etc., some on grass and some on soil; also invert similar vessels, side by side with the former, but on metal plates, slates, or tiles. Compare the results in the two cases, both on clear nights and on cloudy nights.

5. Hoar frost.—(*Outdoor work.*)—Contrast the appearance of hoar frost with that of frozen dew. One covers the pavement with white particles; the other with a glassy sheet of thin ice. Hoar frost is atmospheric moisture condensed *after* the temperature of the surface has fallen below 32° F. Does the formation of hoar frost without frozen dew

indicate a relatively dry or a relatively moist atmosphere? Why? To what extent do your observations support this conclusion? Expose inverted tumblers, earthenware jars, etc., and try to discover whether hoar frost is ever formed on the under surfaces of objects on the ground.

Condensation of water vapour.—The water vapour in the air sometimes becomes visible, assuming one of different forms according to the circumstances bringing about the necessary condensation. Some of the commonest products of this condensation are *dew*, *hoar frost*, *fog*, *mist*, *clouds*, *rain*, *snow and hail.* Since all these phenomena are results of the conversion of the water vapour either into liquid or solid water, it will be desirable to refer briefly to the conditions which result in such condensation.

Evidently condensation and evaporation are exactly opposite processes. Since the absorption of heat is necessary for the conversion of a liquid into a gas, there will be a liberation of heat when the contrary change, from the gaseous to the liquid condition, is effected, or when the gas is condensed. Any process which results in the cooling of air will cause some water vapour to assume one of the states enumerated, and all the circumstances to which we shall have to refer are really methods of bringing about such a lowering of temperature.

Hygrometry.—Air always contains water vapour. The actual quantity it is able to hold depends upon the temperature of the atmosphere. Consequently there will be more present in summer than in winter, although, judging only by the feelings, one would say that the air was drier during summer. This sensation of dryness results from the fact that the air could take up more water vapour than there is in it, since it is at a higher temperature. When the amount of water vapour actually present in the air is compared with the maximum quantity it could take up at that temperature, a measure of the *relative humidity*, or the *hygrometric state* of the air at the time of the experiment is obtained. The hygrometric state or degree of saturation of the air is ascertained by the use of an instrument called a **hygrometer.** There are many kinds of hygrometers.

By passing a known volume of air through a substance which has the power to remove all the moisture from it, such as calcium

chloride or strong sulphuric acid, and noticing how much the dehydrating agent, as it is called, has increased in weight, we obtain a very accurate form of hygrometer, known as the **chemical hygrometer.**

A more usual plan, however, is to use a form of instrument known as **Mason's hygrometer.** It consists of two precisely similar thermometers, suitably attached to a wooden stand as in Fig. 181. Round the bulb of one of the thermometers is tied a piece of muslin to which cotton threads are attached and hang into water kept in a glass, supported as shown. The instrument depends for its use upon two facts. The first is that water is vaporised only at the expense of a certain amount of heat, and secondly, the quantity of water vapour which air can take up at any temperature depends upon the amount already contained by it. Water rises up the cotton threads by capillary attraction, and consequently keeps the muslin moist. The water on the muslin evaporates, getting the heat necessary for evaporation from the bulb of the thermometer which it surrounds. The thermometer is cooled and the column of mercury sinks. This process continues until the air round the bulb is saturated and evaporation ceases. Thus the wet bulb thermometer records a lower temperature than the one with a dry bulb. The drier the air at the commencement of the observation, the greater is the difference between the readings; and a means of estimating the amount of water vapour present is thus obtained by seeing how much more must be added to saturate it.

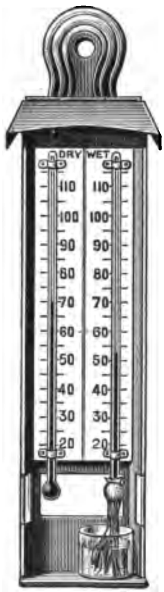


FIG. 181.—Mason's hygrometer.

Dew.—Dew differs from rain, snow and hail in being formed *upon* the surface of the earth. After sunset, the surface of the earth, which has been receiving heat throughout the day, begins to radiate this heat. Different parts of the earth possess differing powers of radiation. Those which during the day absorb heat to the greatest extent radiate it most abundantly after the sun has set, and consequently become cooled more quickly than those of smaller radiating power. Similarly, the air in contact with these bodies also becomes cooled and is then unable to hold as much water vapour as before, and the surplus is deposited in the

form of **dew**. The temperature at which this deposition begins is called the **dew point**.

For an abundant formation of dew several conditions are necessary. First, radiation must go on freely, and this happens on *bright clear evenings* when there are no clouds to obstruct the radiation. The air which is being cooled by contact with the body from which free radiation is taking place must not be disturbed before the dew point is reached, or no dew will be thrown down, that is, the *evening must be still*. A breeze would constantly renew the air above the body being cooled by radiation, and thus prevent the dew point from being reached. The best radiating surfaces are those of leaves, whether of grass or other plants; stones and similar things are also good radiators.

Side by side with this simple condition of things, another process is going on which augments the amount of dew formed. Throughout their life, plants continually give off water in the form of vapour, which is exhaled through the numerous apertures spread over their leaves, especially on the under surfaces. This process, known as *transpiration*, supplies a large amount of water vapour to the air. Dr. J. Aitken has shown that when the cooling spoken of above has gone on for some time, and the dew point has been reached, the transpired moisture, instead of diffusing into the atmosphere in the state of vapour, is condensed at the little apertures on the leaves as soon as it comes into contact with the cooled air. Thus, the dew is not all obtained directly from the atmosphere.

Other considerations in connection with formation of dew.—Colonel W. B. Badgeley made a number of experiments with a view of determining what part both plants and the earth itself take in the formation of dew, as well as of ascertaining whether the amount due to their agency, if any, varies at different times of the year. He arrived at the following conclusions:

1. The earth always exhales water vapour by night, and probably a greater quantity by day.
2. The quantity of water vapour given off by the earth is always considerable, and any variation in the quantity is mainly due to the season of the year.
3. The *greater part of the dew comes from the earth vapour.*

4. Plants exhale water vapour and (in general) do not exude liquid moisture.

This fourth conclusion is of particular interest, since it indicates that the dew formed on plants does not come out of them in the form of actual droplets, but of vapour which is afterwards condensed into liquid water.

These observations and experiments were extended by the Hon. Rollo Russell, who experimented with glass tumblers and pans, which he inverted over grass and bare earth and left out during the night. He invariably found that the interiors of these vessels became covered with a deposit of dew whenever the evenings were clear. With a view of eliminating every objection which could be urged against his conclusions, he inverted similar vessels on earthenware or metal plates placed upon the ground, and in these circumstances dew was never formed on their inside surfaces. In the first case the dew found covering the interior of the vessels probably represented the condensed vapour which had been exhaled from the earth or grass.

Russell showed also that the interior of glasses inverted over grassy turf was always more thickly covered with dew than in the case of those which were placed similarly over a turf which had been robbed of its grass. Plates suspended immediately over grass became more bedewed than similar plates suspended over bare earth, results which might have been anticipated from the greater radiating power of grass added to the amount of moisture transpired.

The deposition of dew is favoured, too, by a humid atmosphere, especially when it is calm. From what has been seen of the fundamental cause of the formation of dew it is clear that free radiation, which is more likely to occur in exposed situations, is most effective in the production of dew. Hence most dew is formed on good radiators, and *whatever diminishes the view of the sky diminishes the quantity of dew.*

Hoar frost—or as it is sometimes called, *white rime*, or simply **rime**—is deposited instead of dew on evenings when the radiation cools the overlying air to the temperature of freezing water before any deposition of moisture takes place. Hoar frost is *not* frozen dew. It does not first assume the liquid condition, but is precipitated at once in the solid form. In these circumstances the dew point is at or below the freezing point.

35. CLOUDS, RAIN, SNOW AND HAIL.

1. Vapour and steam.—(*a*) Watch the steam issuing from the spout of a kettle or the mouth of a flask in which water is boiling. At what distance from the spout does the steam become visible? What is there between the spout and the visible steam? Put a cold object into this space for a moment and observe the drops of water condensed on it. Hold a red-hot poker in the same position until it cools, and describe the effect upon the steam.

(*b*) Observe the space above boiling water inside a glass flask; is it clear or cloudy? Fan, or blow, some cool air into the flask. Explain why the space becomes cloudy for a moment.

(*c*) Leave a small saucer of water inside the receiver of an air pump until the air of the receiver is saturated with moisture. Then work the pump and observe that the air becomes cloudy.

2. Mist and fog.—(*a*) Try to frame definitions of mist and fog, to show in what respects they differ from each other and from clouds. How (i) by a change in your own position, and (ii) by a change in the position of the partly condensed vapour, could a cloud become mist, or mist become a cloud?

3. Cloud forms (*Outdoor work*).—Look for clouds similar in shape and appearance to those shown in Figs. 182 to 185, and in each case decide on the term which best describes the cloud—if necessary using such compound terms as cirro-cumulus, etc. Make a note, for future reference, of the direction in which the cloud was seen, of the direction in which the wind was blowing the smoke of near chimneys, of the direction in which the cloud appeared to be moving, of the kind of weather preceding and following your observation, and of the date and hour of observation.

4. Observation of halos.—Make a dated note of any halos (coloured arcs or circles around the sun or moon) you see; describe this appearance and the character of the weather preceding and following each observation.

5. Rain.—(*a*) *The rain-gauge.*—Obtain a cylindrical vessel, *e.g.* a beaker, a pint mug or a jam-jar, and put in water to the depth of about a quarter of an inch. Given the means (*e.g.* a millimetre scale and a pair of dividers) of obtaining the internal diameter of the vessel, and also of measuring accurately the volume in cubic centimetres of the contained water, devise a method of finding the *depth* of the layer of water in the vessel, assuming the bottom to be flat and horizontal. The area of a circle $=(\text{radius})^2 \times \frac{22}{7}$.

(*b*) Examine a *rain-gauge* and its accompanying measuring-jar (Fig. 186). Its use is to find the *depth* of water falling as rain at any place during any given period (*e.g.* 24 hours) of time. Is it necessary to know the inside diameter of the top of the gauge? of the bottom? How is the measuring-jar graduated? Is the method of graduation a device for saving labour in calculation? If so, explain it. What is the use of the contained funnel? What precautions as to horizontality, nearness to other objects, etc., do you suppose are necessary in using the gauge? Make regular measurements of the rainfall; if you cannot obtain a standard gauge, make a gauge on the principles suggested above, and use it. Plot your results as in Fig. 187.

(*c*) *Rainbows.*—Is a rainbow visible before, during, or after a shower? Is it visible only when the sun is shining, or in "diffused" daylight also? In what direction, relative to the sun, must an observer generally look so as to see a rainbow best? What is the succession of colours (the "spectrum") shown in the bow? Is the red end of the spectrum on the convex or the concave border of the rainbow? Make a special note of any double rainbows seen, or any rainbows of uncommon types?

6. Snow and hail (*Outdoor work*).—(*a*) Several times during the winter allow falling *snow* to fill a cylindrical jar (*e.g.* a large jam-jar); on each occasion note the temperature of the air. Melt the snow, and measure the volume of water produced; measure the internal height and the internal diameter of the jar, and calculate the volume. How many inches of snow are equivalent to one inch of rain? Is the result always the same? If not, is it affected by the temperature? Is snow more loosely or more closely compacted in colder weather? Observe and compare the sizes of snow flakes in very cold and in relatively mild weather. Catch falling snow on black velvet or paper, and examine the flakes with a lens; do you find the most perfectly formed crystals in the coldest weather, or not? On which side of neighbouring hills does the snow remain unmelted latest in the spring?

(*b*) Whenever there is a *hail* storm, collect hailstones of various sizes. Estimate the maximum size, and notice whether the large and the small stones differ in appearance. Melt some stones in cold water and, if possible, others in hot water and look carefully to see whether bubbles of imprisoned air escape from any. Crush other stones, both dry and in water, and observe their behaviour. Try to find out whether the stones are of solid ice, of a shell of ice surrounding a nucleus of snow, or hollow. Write a note of your

results immediately, and add the date. At what season of the year are hail storms most frequent?

Mists and fogs.—The general features of those forms of condensed moisture which are referred to under the names of **mists** and **fogs** are familiar to every one. We naturally associate mists with rivers or other water surfaces; most often they make their appearance after the sun has set. They seem to be caused in this way: the air over the land by the side of the river cools more quickly than that over the river itself, partly because land radiates heat better than water does, and partly because it contains less heat than water at the same temperature (p. 287). The air over the water will show a tendency to rise, and the cold air will move towards the water to take its place. But the air over the water will thus be cooled and will be unable to hold as much water vapour as before, and the excess of moisture assumes the nature of a mist. It is impossible to say when a mist becomes a fog. A fog is generally regarded as something denser and blacker than a mist. At all events, the condensation which forms a fog, and probably a mist also, takes place round the small particles of dust in the air, which act as nuclei for the minute water drops which make up the fog.

Some localities are rarely free from fog, since the permanent conditions are suited so exactly to its formation. Almost perpetual mists and fogs occur, for example, along the coast of Newfoundland, where the air above the warm water of the Gulf Stream, laden as it is with moisture, comes into contact with the air over the cold Labrador current (Fig. 154). Just as a fog is caused by a lowering of the temperature of the air, so if the temperature again becomes raised by any means, the fog will disappear. It is in this way that the mists are cleared away towards noon by the heat of the sun as it rises higher and higher in the heavens.

It is a common experience, in the ascent of a mountain, that mists are encountered as soon as the height attained becomes only a few hundred feet. The condensation of moisture which here causes the mist is the result of the cooling of the air as it is forced up the side of the hill.

Clouds.—Clouds are sometimes formed in a similar manner as mists and fogs. They differ chiefly in their position, and can be correctly regarded as mists high up in the air. When from any cause an upward current of warm air laden with invisible moisture is cooled in the higher regions of the atmosphere, a cloud is produced. This result can be brought about by a warm, moist stratum coming into contact with a cold current of air, whereby it becomes cooled and some of its moisture is condensed into minute particles, which Tyndall called "water dust." Or, in its upward passage, the current of warm moist air naturally comes to a colder zone, and as naturally some of its moisture takes the visible form of a cloud. Moreover, in ascending to levels where the pressure is less, air expands, and is thereby cooled (see Expt. **35** (1) *c*, p. 321); in fact, this cause of cooling is far more effective than the former.

Photo. F. V. Horn.

FIG. 182.—Cirrus cloud.

It is only necessary to watch the ever-changing shapes assumed by clouds during a short period of a breezy summer day to become charmed by their beauty and impressed by their grandeur. An almost infinite number of shapes may be observed at different times, but a continuous study of the sky will show that clouds frequently recur under similar forms, and so admit of being arranged into classes. There is naturally no very definite line of demarcation between one form of cloud

FIG. 183.—Cumulus cloud.
(From a photograph by Dr. W. J. S. Lockyer.)

and another, and several forms may be seen at the same time. Notwithstanding this, a number of clearly marked shapes can be recognised, and have been classified by meteorologists.

FIG. 184.—Stratus cloud.
(From a photograph at Westgate-on-Sea by Dr. W. J. S. Lockyer.)

Classification of clouds.—The system of cloud classification most widely known was published by Luke Howard at the beginning of last century. Three fundamental types (Figs. 182 to 184) were recognised, to which the names **cirrus**, **cumulus**, and **stratus** were given. They may be described as follows:

Cirrus.—Parallel, flexuous, or diverging fibres, extensible in any or in all directions. They may be from 5 to 10 miles high.

Cumulus.—Convex or conical heaps, increasing upward from a horizontal base. Their average height is about 1 mile.

FIG. 185.—Nimbus cloud.
(From a photograph by Dr. W. J. S. Lockyer.)

Stratus.—A low, widely-extended, continuous, horizontal sheet increasing from below.

From these three primary forms Howard devised four intermediate forms, which he named cirro-cumulus, cirro-stratus, cumulo-stratus, and cumulo-cirro-stratus or **nimbus** (Fig. 185).

This nomenclature of clouds is still used by many meteorologists, but it is giving place to another classification adopted by an international meteorological congress,

and therefore termed the international system. Ten different types of clouds are recognised in this system, and are numbered 1 to 10, from the highest form (cirrus) to the lowest (stratus).

As different clouds usually occur at different altitudes, it is easy to understand that they may give **indications of forthcoming weather.** An old proverb says, "The higher the cloud, the finer the weather," and this is probably true in many cases. Of cumulus clouds, it is said:

> "If woolly fleeces spread the heavenly way,
> Be sure no rain disturbs the summer day";

and of the cumulo-nimbus (the "shower cloud"):

> "A round topped cloud, with flattened base,
> Carries rainfall in its face."

A rule which applies to one part of the world may not, however, be accurate for another; nevertheless, when used in connection with observations of temperature and pressure, or with a weather chart (p. 360), cloud forms are of real service in weather forecasting. But, as in all departments of science, little satisfactory progress will be made unless the observer's work is systematic and orderly. It is not enough to admire the ceaseless succession of sky patterns which have been mentioned. Each observation should be at the time recorded with the notes and sketches necessary to make it intelligible when referred to at some future time. If this is conscientiously done for a few weeks, the student who makes such a cloud record will be surprised to find order presenting itself out of diversity, and regularity where only confusion seemed at first to prevail.

Rain.—The particles constituting a cloud, that is, the water dust already spoken of, continually tend to coalesce or unite together to form larger drops. When drops reach a certain size the air can no longer support them in consequence of their increased weight, their surfaces not having increased in the same proportion,* and they fall, since they oppose less relative resistance to the air. They do not always reach the surface of the earth, however, for in their downward course it may happen that they

*The weight of a sphere is proportional to its *volume*, which is $\frac{4}{3}\pi r^3$. The *surface* of a sphere is $4\pi r^2$.

have to traverse a layer of dry, unsaturated air, when the drops may become wholly evaporated again. In their passage through very moist air, then, rain-drops continually get larger, whereas in falling through dry air they become smaller until they may even eventually disappear.

Principal causes of rain.—Rain is always caused by **the cooling of air containing moisture,** but this cooling may be effected in a variety of different ways. The following are stated by Dr. R. H. Scott to be the principal:

1. The ascent of a current of damp air into the colder and rarer regions of the atmosphere.

2. The contact of warm and damp air with the colder surface of the ground, as in the case of our own west coasts in winter, where the land is colder than the sea surface.

3. The mixture of masses of hot and cold air.

With reference to the first of these causes it must be borne in mind that the ascending air is cooled, not only by its passage into colder regions, but also by the expansion it experiences consequent upon the diminished pressure of these higher strata. The results of such expansion can be shown by a simple experiment (Expt. **35** (1) *c.*).

Measurement of rainfall.—Of all the forms of condensed moisture which have now been described the most important, because it is the commonest and most abundant, is rain. We have next to consider how the amount of rain which falls in a place is measured and estimated. This amount is spoken of as the **rainfall** of a place. The student has doubtless often come across the statement that the annual rainfall of a certain place is so many inches. Thus, he may have seen that the mean annual rainfall of Nottingham is twenty-five inches. By such a statement is meant that, could all the rain which falls upon a particular area in that town be collected, none being lost, the amount which would accumulate during an average year would be sufficient to cover the area to a depth of twenty-five inches.

For measuring the amount of rain which falls in a locality a simple instrument called the **rain-gauge** is used. There are many patterns of rain-gauges, but the object of them all is the same, viz. to collect all the rain falling on a known area, and store it in such a

way that there is no loss by evaporation. A satisfactory form is that shown in Fig. 186, and its construction will be at once understood by reference to the diagram. It consists of a metal cylinder, in which a funnel fits accurately and directs the rain into a receiving vessel. The graduated jar, by the side of the gauge, is used to measure the amount of rain collected during the previous twenty-four hours from the time of setting the instrument. The upper edge of the cylinder has a sharp rim, so that the area receiving the rain collected is known with accuracy, and also the exact relation between it and that of the graduated vessel in which the water is measured. When, in addition, the amount of rain has been measured we have all the information necessary for calculating the rainfall of the place.

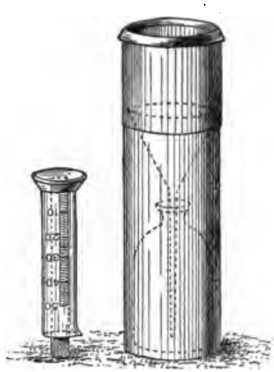


FIG. 186.—A rain-gauge.

In speaking of the manner of recording the amount of rain, the expression *mean annual rainfall* is often used, and it will be desirable to make it clear what is thereby meant. One year may be much wetter than another, *e.g.* during 1872 a very large amount of rain fell in this country, whereas in the following year the rainfall was unusually small. Thus, by taking any one year we may get an entirely wrong estimate of the amount of rain which generally falls at a place, and to avoid this it

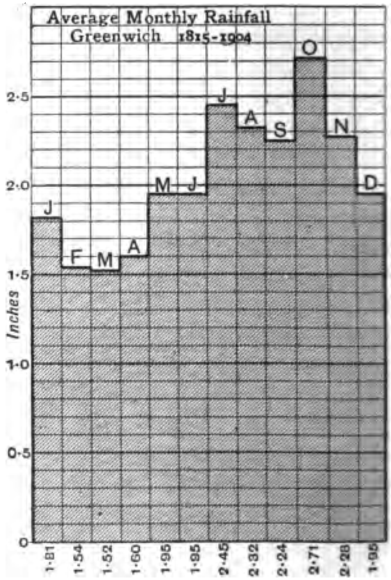


FIG. 187.—Average monthly rainfall at Greenwich from 1815 to 1904.

is usual to add the amounts of rainfall for several successive years together and divide by the number of years, thus obtaining the average for the years taken; such a result is known as the mean annual rainfall of the place. Fig. 187 shows graphically the mean monthly rainfall at Greenwich from 1815 to 1904. The mean annual rainfall of the place is of course the sum of the separate monthly averages.

Snow.—Sometimes the temperature of a cloud is below the freezing point of water, when it is manifestly impossible for the moisture to assume the liquid state, and it becomes condensed in a solid form. If, in addition to this, the temperature of the air

FIG. 188.—Photomicrographs of snow crystals.

through which the descending solid particles pass is below the freezing point, we shall have a fall of solid particles in the form of **snow**. The falling particles unite continually to build up larger masses which we know as **snow-flakes**, which, under favourable conditions, assume the most beautiful forms (Fig. 188). Ice crystallises in *hexagonal* forms, and snow-flakes are found on examination to be skeleton combinations of minute crystals of this kind. In this country the crystals are seen best when a fall of snow takes place in a still, quiet atmosphere, with the temperature at 0° C., or lower, to prevent a partial thaw from ruining their exquisite beauty. If the snow in its descent upon the earth becomes partly melted, and perhaps later partly frozen again, instead of snow-flakes reaching the surface we shall have a mixture of half-melted snow and rain, which is called **sleet**.

Where the temperature of the atmosphere at the surface of the

earth is never so low as the freezing point, snow cannot fall, for it will be melted before reaching the earth. Such a condition of things is found within the tropics, and extends to a distance of about 30° N.; while south of the equator, the limit is farther removed from the equator towards the Antarctic regions.

In high latitudes the average temperature is always below the freezing point, and snow exists on the ground all the year round. **That level, in any latitude, above which snow is found always, is called the snow-line.** This line touches the surface near the poles and attains its highest elevation in the tropics, where it never gets nearer than about 13,000 feet to the sea level (Fig. 93).

Hail.—The mode of formation of hail-stones has never been satisfactorily explained. In our country hail falls more commonly in summer and spring than during the winter months. Its existence seems in some way to be connected with the electrical state of the atmosphere. However it may be formed, it is another instance of the condensation of atmospheric vapour in the solid state. Hail-stones take the form either of hard or soft pellets, which vary in size from a small pea to a small hen's-egg. Just as rain-drops and snow-flakes commonly increase in size as they approach the earth's surface, so do hail-stones aggregate together in their downward flight, becoming larger and larger as they reach their destination.

An examination of hail-stones at different times and in various places has shown that they vary in their nature. Sometimes, when a hail-stone is cut through, it is seen to be deposited round a speck of dust as a nucleus and to take the appearance of having been built up gradually, and not formed *en masse*, but exhibiting a more or less stratified structure.

Soft hail-stones resemble small lumps of snow without any central dust particle.

Prof. Cleveland Abbe suggests* that they may have been formed by the sudden freezing of drops of pure water (*i.e.* water containing not even dissolved air) which have been cooled to a temperature below 32° F. It is possible to cool pure water to a temperature below its normal freezing point, but it suddenly turns to ice and then the temperature instantly rises to 32° F., the mass assuming a crystalline structure so as to resemble snow.

* "Structure of Hailstones," *Monthly Review*, 1908.

As to the origin of the snowy ice at the centre of a *hard* hail-stone, Prof. Abbe points out that there are two plausible hypotheses:

"(*a*) The hail-stone may have begun with the formation of a ball of snow, and the clear ice may be a deposit of cold water, frozen a few seconds later by the cold of the surrounding atmosphere." In this case the snowy ice at the centre would contain compressed air, which would be liberated when the stone melted.

FIG. 189.—Hail-stones, whole and in section. (Reproduced from the *Meteorologische Zeitschrift.*)

"(*b*) The nucleus of the hail-stone may have been at first a large drop of water, containing dissolved air, which is forced out by the process of freezing, precisely like the bubbles of air that are seen in cakes of artificial ice." Such air would be reabsorbed by the water on slow melting of the hail-stone.

Total precipitation.—The "total rainfall" of a place is considered to include all forms of precipitated moisture, whether rain, snow or hail, which can be measured.

The distribution of rainfall is so directly dependent on prevailing winds that it cannot be dealt with satisfactorily before the movements of the atmosphere have been studied. Rainfall distribution is therefore considered in Chapter XV.

EXERCISES ON CHAPTER XIII.

1. How are fogs and mists formed, and why are they specially prevalent on the sea coast and at high elevations?

2. What is a cloud? Describe the appearance of the chief types of clouds. Illustrate your answer by sketches. (C.S.)

3. How is a cumulus cloud formed? Why are mountain peaks often surrounded by clouds when the rest of the sky is clear? (C.S.)

4. What is an inch of rain? Describe the construction and method of use of one form of instrument for measuring it. (C.J.)

5. What are the differences between rain, hail and snow? How do these differences arise? (C.J.)

6. Explain the formation of fog and mist. Why is fog or mist especially common (*a*) on mountain tops, (*b*) in marshy lands, (*c*) in London? (C.S.)

7. Taking the average annual rainfall of England, Scotland, Ireland, Wales and the United Kingdom as 32·5, 47, 42, 49, and 39 inches respectively, construct, on squared paper, a diagram illustrating clearly the difference between them.

8. What causes rain? How is rain measured? The average monthly rainfall of a certain place from January to December is given in inches as 1·9, 1·5, 1·2, 1·5, 1·9, 2·3, 2·2, 2·3, 1·6, 2·3, 1·8, 2·1. Would you call this a *wet* place?* Give reasons for your answer, comparing its rainfall with that of any other district you know. Convert the figures given into a diagram. (L.J.S.)

9. What causes tend to produce fog? Do you know any regions where fog abounds? Explain the causes in each case.

10. How is rainfall measured? What special precautions are necessary in the construction and use of a rain-gauge to ensure accuracy? (N.F.U.)

11. Name the different kinds of clouds, with some account of how the weather can be predicted from their appearance. (N.F.U.)

* See Fig. 214.

CHAPTER XIV.

THE ATMOSPHERE AND ITS MOVEMENTS.

36. THE PRESSURE OF THE ATMOSPHERE.

1. The weight of air.—Fit a one-holed indiarubber stopper into a fairly large glass flask, and fit into the stopper a short tube with a stopcock upon it. Put a little water in the flask, open the stopcock, and boil the water. After boiling for a short time turn off the tap, and place the flask on one side to cool. When the flask is cool, weigh it, or counterpoise it. Then open the stopcock; air will be heard to rush into the flask, and as it does so the balance will show an increase of weight.

2. The pressure of the atmosphere.—Procure a thin tin can having a neck, into which fits an indiarubber stopper. Take out the stopper and boil a little water in the can. After the water has been boiling for some time, so that the can is practically filled with steam, remove the can from the flame, and quickly put in the stopper as tightly as you can. After a few minutes the can will collapse inward. Why? Why did the air rush into the flask in Expt. 1 above, when the stopcock was opened?

FIG. 190.—Experiment illustrating the pressure of the atmosphere.

3. The principle of the mercurial barometer.—(*a*) Take a tumbler or cylinder with ground edges and completely fill it with water. Place a piece of stout writing paper across the top and invert the vessel. If the air has been excluded carefully from the cylinder the water does not run out (Fig. 190). Think what keeps the paper in its place.

(*b*) Procure a thick glass tube about 36 inches long and closed at one end. Fill the tube with mercury, place your thumb over the open end, invert the tube, place the open end in a cup of mercury and take away your thumb. A column of mercury will be supported in the tube. What keeps it in position? Measure the difference in height between the top of the mercury column and the level of the mercury in the cup.

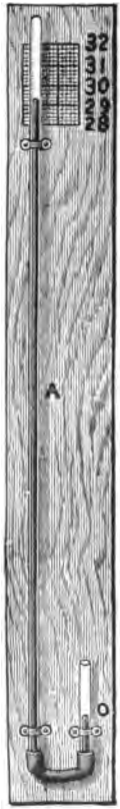


Fig. 191.—To explain the principle of the barometer.

(*c*) Fit a short piece of indiarubber tubing on the open end of a tube similar to that used in the last experiment (*b*). Tie the free end of the tubing to a piece of glass tube about six inches long open at both ends. Rest the barometer tube with its closed end downwards and pour mercury into it (being careful to remove all air bubbles) until the liquid reaches the short tube. Then fix the arrangement upright as in Fig. 191. What is the difference in height of the tops of the mercury columns in the two limbs? Empty the apparatus; then measure out this depth of mercury in the long tube, and weigh the mercury. Measure also the inside diameter of the tube; the area of the cross-section of the mercury column $=$ radius$^2 \times 3\frac{1}{7}$. What would be the weight of the mercury column, supported by the pressure of the atmosphere, in a tube of 1 square inch cross-section? What is the pressure of the air, measured in pounds, per square inch?

4. Variation of barometric pressure.—Read the height of the barometer daily at the same hour for a month or longer, and keep a record of the heights and of the state of the weather (see Expt. 3, p. 344). Does the weather change before, with, or after the barometer?

5. Finding heights by means of a barometer.—Would you expect a barometer reading taken at the top of a mountain to be higher or lower than one taken at the foot at the same time? Why? The following approximate heights and barometer readings are said* to correspond when the barometer reading at sea level is 29·921 inches and the temperature of the intermediate air is 32° F.:

* Lt.-Col. Close's *Text Book of Topographical Surveying* (Wyman).

Boiling point of water.	Barometer reading (inches).	Height (feet).	Boiling point of water.	Barometer reading (inches).	Height (feet).
°F.			°F.		
212	29·921	—	203	24·952	4741
211	29·329	522	202	24·447	5278
210	28·746	1046	201	23·950	5815
209	28·174	1571	200	23·461	6354
208	27·613	2097	199	22·980	6895
207	27·062	2624	198	22·507	7439
206	26·521	3151	197	22·042	7984
205	25·989	3680	196	21·584	8533
204	25·466	4210	195	21·133	9084

Calculate in several instances the difference in altitude corresponding to a difference of 1 inch barometer reading. Is the proportion approximately constant? If not, does it increase or decrease regularly with the altitude? Do you consider the rule for moderate elevations, "*900 feet altitude per inch of barometer height,*" a satisfactory one?

Test by the same table Clerk Maxwell's rule :* "*For rough purposes the differences of the logarithms of the heights of the barometer multiplied by 10,000 gives the difference of the heights in fathoms of six feet.*"

The mean annual barometric pressure at the summit of Ben Nevis is 25·3 inches; at Fort-William (sea level) it is 29·8. Find the approximate height of the mountain, given log 29·8 = 1·4742, log 25·3 = 1·4031.

A barometer at the top of a mountain known to be 4256 feet high read 25·51 in. and at the bottom 29·81 in. The temperature at the top was 50·5° F. and at the bottom 63° F. Applying Clerk Maxwell's rule:

$$\log 29{\cdot}81 = 1{\cdot}4743$$
$$\log 25{\cdot}55 = 1{\cdot}4074$$
$$\therefore \text{Height} = 0{\cdot}0669 \times 10{,}000 \times 6 = 4014 \text{ feet.}$$

How do you account for the discrepancy? Why ought such barometer readings to be corrected for temperature?

6. Aneroid barometer.—Examine a pocket aneroid (Fig. 19), and notice the scale of feet accompanying the barometer scale. Make as many height determinations with it as possible, and compare them with the results obtained by Clerk Maxwell's rule, neglecting temperature.

* *Theory of Heat* (Longmans, 3s. 6d.).

The atmosphere.—Surrounding the earth in every latitude, over land and sea, is a gaseous envelope which is spoken of as the air or the atmosphere. Its presence when at rest is unperceived, though when moving it becomes apparent, since it imparts its motion to leaves and other bodies free to move.

Its existence may be demonstrated equally well in various other familiar ways. If a so-called "empty" bottle is inverted carefully in water, the water does not go in, because the bottle is already full of air. If the bottle is tilted, the air escapes as bubbles, and water takes its place inside the bottle. A person moving quickly across a room with a large sheet of paper or cardboard in his hands feels little or no resistance when the cardboard is held "edge on," but finds his motion impeded when he holds it "broad-side on."

Weight of the air.—Expt. 1 in this section affords an easy proof that air has weight. If the air is removed completely from a flask by means of an air-pump, the difference in the weighings, before and after, will provide the exact weight of a given volume of air. Thus, if the vessel has a capacity of a cubic foot, the difference of weight will be found to be nearly an ounce and a quarter.

Pressure of the atmosphere.—It is a property of all gases and liquids that they communicate pressure in all directions. If the atmosphere did not possess this property, instead of lying quietly on the ground, a fallen leaf would move off in the direction of least pressure, which would evidently be upwards. It is a consequence of this circumstance, too, that we are able to move about quite freely. Our bodies are subjected to an enormous pressure due to the whole weight of the atmosphere above us, and yet we are quite ignorant of it, at all events in ordinary circumstances. Why is this? The lungs which fill up a large part of our chest capacity are inflated with air. The inside air is under just the same pressure as that outside, and consequently there is an exact compensation, and we are not crushed.

The result of atmospheric pressure on a vessel having practically no compensating inside pressure is well shown in Expt. **36**, *2*. The explanation of the effect produced in this experiment is that as the can cools, nearly all the steam inside is condensed

into water, and so occupies a much smaller volume. The pressure which this steam exerts on the inside of the can is thus removed, while the pressure of the air on the outside remains practically the same, the result being that the can is crushed. At the sea level, under ordinary conditions, the pressure of the air is about 15 lbs. on every square inch.

Another familiar illustration of the pressure of the air in all directions is found in a boy's leathern sucker. The difficulty of removing the sucker by a pull at right angles to the surface on which it has been pressed, is found to be the same whether the surface is horizontal, vertical, or oblique, facing upwards, or facing downwards. It is the pressure of the air which forces water into a syringe or squirt when the open end is placed in water and the piston is pulled up. It is the upward pressure of the air which balances the weight of the water filling a tumbler, which has been covered by a sheet of paper and then inverted (Fig. 190).

Principle of the mercurial barometer.—It has been seen that the air has weight, and that it exerts great pressure on the earth's surface; we have now to learn how this pressure is measured. In Expts. **36**, 3, *b* and *c* (Fig. 191) the mercury in the long tube will be seen to fall so as to leave a space of a few inches between it and the closed end. The distance between the top of the mercury column in the closed tube and that in the open tube will be found to be about thirty inches.

On reference to Fig. 191, it is clear that there is a column of mercury supported by some means which is not at first apparent, or else the mercury would sink to the same level in the long and the short tube, for we know that liquids tend to find their own level. If a hole were made in the closed end of the tube this would happen immediately. The column of mercury is kept in its position by the weight of the atmosphere pressing upon the surface of the mercury in the short open tube. The weight of the column of mercury and the weight of a column of the atmosphere with the same sectional area is exactly the same; both columns are measured from the level of the mercury in the short limb of the barometer shown in Fig. 191, the mercury column to its upper limit in the long tube, the air column to its upper limit, which is a great distance from the surface of the earth, and probably very indefinite. If for any reason the weight of the atmosphere becomes greater, the mercury will be pushed higher to preserve the balance; if it should become

less, then similarly the amount of mercury which can be supported will be less, and so the height of the column of mercury is diminished.

The student will now understand why it is necessary to remove all the air bubbles in Expt. **36**, 3, *c*. If this were not done, when the tube was inverted the enclosed air would rise through the mercury and take up a position in the top of the tube above the mercury. The reading would not then be thirty inches, for instead of measuring the whole pressure of the atmosphere, what we should really be measuring would be the difference between the pressure of the whole atmosphere and that of the air enclosed in the tube.

An arrangement like that described constitutes a **barometer**, which we can define as **an instrument for measuring the pressure exerted by the atmosphere.**

The height of the mercury column, which is sustained by the pressure of the air, is independent of the width of the barometer tube.

If the tube had an area of exactly one square inch, there would be thirty cubic inches of mercury in a column thirty inches long; and since a cubic inch of mercury weighs about half a pound, the whole column would weigh about fifteen pounds. This column balances a column of air of the same area, so that we find that the weight of the column of air upon an area of one square inch is about fifteen pounds when the barometer stands at thirty inches.

Barometers as weather glasses.—The only direct measurement we can make with the barometer is that of the weight of the atmosphere. Since, however, this weight is influenced by a variety of circumstances which affect the weather, these variations of the atmosphere's weight can supply information respecting the probable weather conditions. If the atmosphere is warm and laden with moisture, it is lighter bulk for bulk than cold dry air would be. The prevalent south-west winds which influence the climate of these islands greatly affect also the upper regions of the atmosphere, warming them and saturating them with moisture, before we become aware, by the weather changes they produce, that they have arrived on the surface. But the whole extent of the atmosphere influences the height of the barometer, and consequently the changes brought about high up in the air, though they cause no change in the weather at the moment, do produce a difference in the weight of the atmosphere, lightening it, and causing the barometer to sink. Soon after

come the corresponding weather changes, which are later results of the cause which brought about the change in the barometer reading. The barometer thus indicates what the weather is likely to be.

Why mercury is used for barometers.—The use of mercury for barometers is a matter of convenience. Since the column of mercury which the atmosphere is able to support is 30 inches high, it is clear that, as water, *e.g.*, is 13·6 times as light as mercury, the column of water which could be supported would be $30 \times 13{\cdot}6 = 408$ inches $= 34$ feet, which would not be a convenient length for a barometer. The length of the column of glycerin which can be similarly supported is 27 feet. But in the case of lighter liquids like these, any small variation in the weight of the atmosphere is accompanied by a much greater alteration in the level of the column of liquid, and in consequence it is possible to measure such variations with much greater accuracy. For this reason barometers are sometimes made of glycerin.

Pressure of the atmosphere at different altitudes. — The atmosphere being a material substance, the longer the column of it which is above the barometer, the greater will be the weight of that column, and the greater the pressure it will exert upon the mercury in the barometer. Hence, as we ascend through the atmosphere with a barometer, we reduce the amount of air above which is pressing down upon it, and in consequence the column of mercury the air is able to support will be less and less as we ascend. On the contrary, if we can descend from any position, *e.g.*, down the shaft of a mine, the mercury column will be pushed higher and higher as we gradually increase the length of the column of air above it.

Since the height of the column of mercury varies thus with the position of the barometer, it is clear that the variation in its readings supplies a means of ascertaining the height of the place of observation above the sea level, provided we know the rate at which the height of the barometer varies with an alteration in the altitude of the place. The application of this principle in map-making has been explained on page 28.

The rule which expresses **the relation between atmospheric pressure and altitude** is not a simple one. When the air intermediate between the two places of observation is at a

temperature of 32° F., the barometer falls, on the average, **about one inch for an ascent of every 900 feet** between sea level and a height of 1,500 feet. Above this height the additional elevation required to produce a fall of an inch in the barometer becomes increasingly greater. It is, in general, more satisfactory to apply **Clerk Maxwell's rule**: "For rough purposes, the differences of the logarithms of the heights of the barometer multiplied by 10,000 gives the difference of the heights in fathoms of 6 feet." If accurate results are necessary, this rule also requires to be modified when, as is nearly always the case, the temperature of the intervening air is other than 32° F.; for a variation of temperature naturally causes expansion or contraction of the parts of the barometer as well as of the air affecting it. From these considerations it is evident that if barometer readings are to be used with any confidence for forecasting the weather, the height of the place of observation and the temperature must both be allowed for. It is for this reason that, in the Daily Weather Reports issued by the Meteorological Office, the barometer readings have all been "reduced to 32° F. and mean sea level ('M.S.L.')."

A second method of finding approximate heights is by observing the temperature at which water boils. As was explained in Chapter XII. (p. 278), the less the atmospheric pressure upon it, the lower is the temperature which suffices to boil water, and *vice versa*. When the temperature of the intervening air is 32° F., the boiling point of water decreases fairly regularly at the rate of 1° F. for each 525 feet, up to altitudes of 4,000 feet. (See Table, p. 335.)

Variation in density of air.—The volume of a given amount of air becomes *greater* as its **temperature** is *increased*, and becomes less as its temperature is decreased. In other words, an increase of temperature results in a decrease in the density of the air, while a decrease of temperature results in an increase of its density.

Changes in volume, however brought about, cause corresponding changes in density. By doubling the pressure on a portion of air, its volume is halved; by trebling the pressure the volume is reduced to one-third, and so on. This relation was discovered by Boyle, and is known as **Boyle's Law**. It can be expressed by saying that *when the temperature remains the same, the volume of a gas varies inversely as its pressure*. Or, what is the same thing, *the temperature remaining the same, the product of the pressure into the volume is constant.*

But it is plain that if we increase the volume occupied by a given mass of a substance we decrease its **density**, or if we decrease its volume we increase its density. Thus, increase of density and increase of pressure are proportional to one another.

It is not difficult to apply these facts to the case of the atmosphere. The pressure of the atmosphere decreases as we ascend, and its density decreases at the same rate. Therefore the densest atmosphere will be that at the surface of the earth (if we leave out of consideration the air of mines and other cavities below the surface, where the air will be denser still). The air gets less dense or rarer as we rise above the surface of the earth, until eventually it becomes so rare that its existence is practically not discernible.

The pressure of the air varies in the same place.—That this is the case every one knows. If it were not so, the reading of the barometer would always be the same in any place, and the pressure being once recorded there would be no further use for the barometer there. We must now consider the reason of this variation. It follows naturally from the facts already stated that:

(1) An increase of temperature produces a diminution in the density of the atmosphere, and consequently a diminution of pressure, which is accompanied by a fall in the barometer.

(2) Water vapour is lighter than air in the proportion of 9 to 14·5. Consequently, if there is a large amount of water vapour present in the atmosphere at a place, the barometric pressure exerted will be less, since the air is thereby made lighter, bulk for bulk.

Thus the rule will be that, other circumstances remaining the same, an increase of temperature will be accompanied by a fall in the barometer; *i.e.* **where the thermometer is high the barometer is low.** Similarly, with the same reservation, an increase of the amount of water vapour in the air will cause a lower barometer reading. In order to map the pressure of the atmosphere in different parts of the world it is usual to draw lines through all those places which have the same barometer reading at any given time. Every morning, observers in the chief towns of this country, as well as of those on the continent, telegraph the height of their barometers to a central office in London. These numbers—reduced to 32° F. and M.S.L.—being placed against their respective towns on a map, it is quite easy to join those places where the pressure is the same at the particular time of observation. Lines so obtained are called "equal pressure lines," or **isobars** (Figs. 200 and 201).

Height of the atmosphere.—Mont Blanc is not quite three miles high, and the height of the barometer at its summit is only about fifteen inches instead of the thirty at the sea level; therefore, the pressure of the atmosphere is only one-half, and the density is consequently one-half; or a cubic foot of air, instead of weighing one and a quarter ounces, would there weigh five-eighths of an ounce. The highest point ever reached by balloonists up to the present is something over seven miles. Messrs. Coxwell

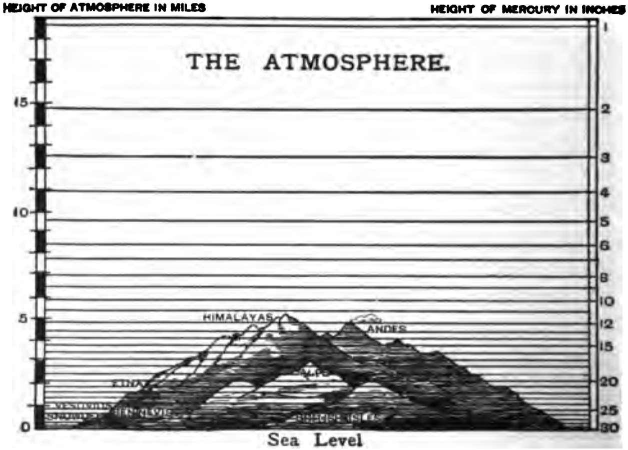


Fig. 192.—To show the height of the barometer at different altitudes.

and Glaisher reached this altitude in 1862, and the atmosphere at that height was so rare that they could not breathe properly, and one became unconscious.

But there are ways by which the presence of the atmosphere can be demonstrated at much greater distances from the earth's surface. Bearing in mind that light is refracted or bent on passing from a rarer into a denser medium, it will not be difficult to understand that the sun always appears higher in the heavens than it really is, for in Fig. 193, when the sun appears to an observer at *A* to be rising at *S′* it is really at *S* below the horizon. If it appears to be at *S″*, and therefore setting, to an observer at *B*, it really has set at some previous moment. Thus, even after the image of the sun is no longer visible, rays of light

reach the observer because of this refracting power of the atmosphere. It is possible from these considerations, which account for the phenomenon of **twilight** before sunrise and after sunset, to demonstrate the presence of air at a distance of forty-five miles from the earth's surface.

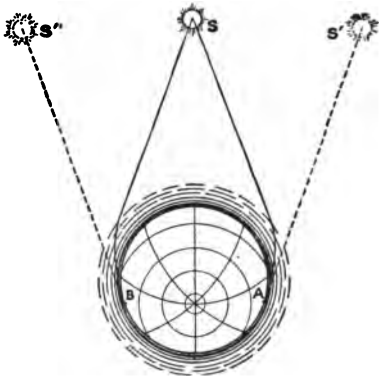


FIG. 193.—To show how atmospheric refraction causes the sun to be visible when below the horizons of A and B.

The phenomena of meteors or shooting stars also provide the astronomer a means of proving the existence of air at still greater heights. These meteors become luminous by the heat developed in consequence of the friction between the meteor and the air particles. The absence of air means the development of no heat of friction, and as a consequence the emission of no light. Just as soon as the meteor can be seen, therefore, we know it has begun to collide with air particles or to have entered the earth's atmosphere, and a measurement of its distance from the earth, which has been found to be about 200 miles, gives the extent of an atmosphere of sufficient density to bring about these results.

FIG. 194.—Experiment illustrating the cause of winds.

37. WINDS

1. The cause of winds.—Open the door of a warm room very slightly, so that only a narrow chink is left (Fig. 194). Then hold a lighted taper to the chink, first near the floor and then higher and higher until it is at the top. Describe the behaviour of the flame. Test the chink at different heights with a thermometer. How do you account for the draughts?

2. Direction of the wind.—(*a*) Estimate the direction of the wind by the weathercock, or by the drift of smoke, if any, at the same hour

each day for a month, and keep a record. At the end of the month represent the result by a diagram (called a "wind rose") as follows: Draw lines through the same point at angles of 45° and mark them N., N.E., E., S.E., S., S.W., W., N.W. to indicate the points of the compass. Make the length of each line, measured from the centre, proportional to the number of observations of winds blowing *from* that direction, during the month, letting, say, ¼ inch represent one observation. Draw a separate horizontal line of length to show the number of observations of "calm." Draw a similar wind rose for each month in the year.

Add up the total number of observations of each wind direction during the year, and calculate what percentage it is of the whole number of observations; make a diagram of the results of the year's observations, letting ¼ in. indicate one per cent.

(*b*) From the information given in the table on p. 345, draw diagrams for January, April, July, October and the whole year, of the percentages of wind direction of the station nearest your district, and compare the results with your own observations. Is the topography of your district likely to modify the direction of the wind very much?

(*c*) What is the *prevailing* wind direction at each station, (i) in each month given, (ii) during the year as a whole?

3. Wind direction and weather.—With what types of weather are the various wind directions usually associated in your neighbourhood? Note the character of the weather daily by the abbreviations used in the Daily Weather Reports:

b. blue sky;	*bc.* sky half clouded;
c. sky three parts clouded;	*d.* drizzling rain;
e. wet air, without rain falling;	*f.* fog;
g. gloomy;	*h.* hail;
l. lightning;	*m.* misty (hazy);
o. overcast;	*p.* passing showers;
q. squally;	*r.* rain;
s. snow;	*t.* thunder;
u. ugly, threatening;	*v.* visibility, unusual transparency;
w. dew;	*x.* hoar frost;
z. dust haze, or smoke.	

Mark the various wind directions in each of your monthly wind roses with the letters you have found to be most applicable to them during the month.

4. Observations of strength of wind.—Estimate the force of

PERCENTAGE OF THE DIRECTION OF THE WIND.*

	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calm.
Aberdeen									
January -	1	1	2	9	28	18	19	10	12
April -	7	8	15	20	17	5	5	13	10
July - -	5	7	5	9	17	10	12	19	16
October -	5	0	2	13	19	12	16	20	13
Year -	5	4	6	11	19	13	14	16	12
Glasgow									
January -	2	8	12	7	15	20	10	2	24
April -	4	27	23	5	6	11	6	2	16
July - -	0	12	9	2	6	23	30	5	13
October -	3	13	9	6	9	17	15	3	23
Year -	3	15	13	4	9	18	15	3	20
Buxton									
January -	7	8	13	7	2	11	24	20	8
April -	5	7	20	18	5	12	18	12	3
July - -	5	4	7	6	1	13	18	44	2
October -	4	7	12	11	2	16	17	25	6
Year -	6	7	12	9	·2	12	21	26	5
Valencia									
January -	2	6	11	17	20	13	11	5	15
April -	10	11	11	15	10	10	9	9	15
July - -	15	3	2	5	12	11	19	22	11
October -	8	13	7	10	14	8	13	8	19
Year -	10	7	6	12	13	12	14	11	15
Ramsgate									
January -	6	18	7	1	13	16	13	6	20
April -	8	24	11	4	10	22	8	4	9
July - -	4	10	9	3	11	33	16	7	7
October -	5	14	8	3	13	19	15	6	17
Year -	6	15	7	3	10	26	13	7	13
Falmouth									
January -	11	8	11	13	15	16	11	9	6
April -	11	10	11	9	13	13	16	11	6
July - -	5	3	5	5	7	17	27	22	9
October -	9	10	12	9	13	10	16	12	9
Year -	10	6	9	7	11	15	18	16	8

* From the *Quarterly Journal of the Royal Meteorological Society.*

the wind daily and note it by the Beaufort number according to the following table:

Force	0	Calm.
„	1	Light air.
„	2	Very light breeze.
„	4	Moderate breeze.
„	5	Fresh breeze.
„	6	"Half a gale."
Force	7	Moderate gale.
„	8	Fresh gale.
„	9	Strong gale.
„	10	"Whole gale."
„	11	Violent storm.
„	12	Hurricane.

Or make use of the following scale in estimating the force of the wind:

1. Light, 2 to 5 miles per hour, moving leaves.
2. Moderate, 7 to 10 miles, moving branches.
3. Brisk, 18 to 20 miles, swaying branches, blowing up dust.
4. High, 27 to 30 miles, swaying trees, blowing up twigs.
5. Gale, 45 to 50 miles, breaking branches, loosening bricks, signs etc.
6. Hurricane, 75 miles or more, destroying buildings and similar structures.

From which direction do the strong winds, moderate winds and light breezes respectively, blow?

General remarks.—That the air is in movement is a fact of common knowledge. The results of its motion can be seen by watching the branches of trees swaying to and fro. The impact of the air particles upon the face can be felt by turning towards a strong breeze. Is there any regularity or order in the way in which winds blow? What causes them? These and a host of other questions present themselves here. Before attempting an answer to such queries, it will be convenient to direct attention to the way in which winds are named. In describing the direction of ocean currents, a northerly current is one which flows toward the north, or similarly with any other. But the contrary is true of winds.

The direction of an ocean current is always given as that point of the compass to which it flows, whereas that of a wind is always spoken of as that from which it blows.

The cause of winds.—Water always flows from a place of high pressure to one where the pressure is lower. It "seeks its own level." Similar movements take place in all liquids and gases;

there is in every case a movement from a point of higher to one of lower pressure until the pressure is equalised. But the pressure of the atmosphere varies from place to place, and since air is a fluid there naturally is a disturbance of the whole, resulting from the readjustment of pressure. *The air moves from the places where the pressure is high towards those spots where the pressure is low.* These movements constitute winds. The winds are *permanent* if the difference of pressures causing them continues throughout the year. They are *periodic* if the pressure differences only arise at definite intervals. *Variable* winds result from any pressure disturbance which may ensue from local peculiarities of situation or from any other cause. Variations in pressure are the result of **alterations in temperature** and of the increase or decrease of the amount of water vapour held by the air. These alterations are, in consequence, to be regarded as the primary causes of winds.

The surface pressure of the atmosphere is least (1) just north of the equator, (2) approximately along the Antarctic Circle, (3) along an ill-defined and varying line bordering the Arctic Ocean on the south. **The districts of greatest surface pressure** occur approximately along lats. 35° N. and 30° S. respectively (Fig. 199); they are known as the *horse latitudes*. The position of these belts of high pressure is apparently a result of mechanical forces set up by the earth's rotation. It is manifest that there will be a movement of air from the belts of high pressure towards those of low pressure. In the northern hemisphere, winds will blow from the northern belt of high pressure towards the equator, and from the same belt towards the pole; while in the southern hemisphere there will be winds towards the equator from the corresponding "horse" latitude, and from the same latitude to the Antarctic Circle. Similarly, there will be outward currents from the poles to the low-pressure belts girdling them.

The trade winds.—The *directions* of these winds are modified, however, by the earth's rotation. The poles are at rest while places on the equator are performing a journey of 25,000 miles in 24 hours, that is, are moving with a velocity of over a thousand miles an hour. Other places on the surface have a velocity intermediate between these two extremes and dependent upon their latitude. Bearing this in mind, we must refer back to the wind in the northern hemisphere, which blows between the northern high-

pressure belt and the equator, and would be a north wind were the earth at rest. The air moving towards the equator is

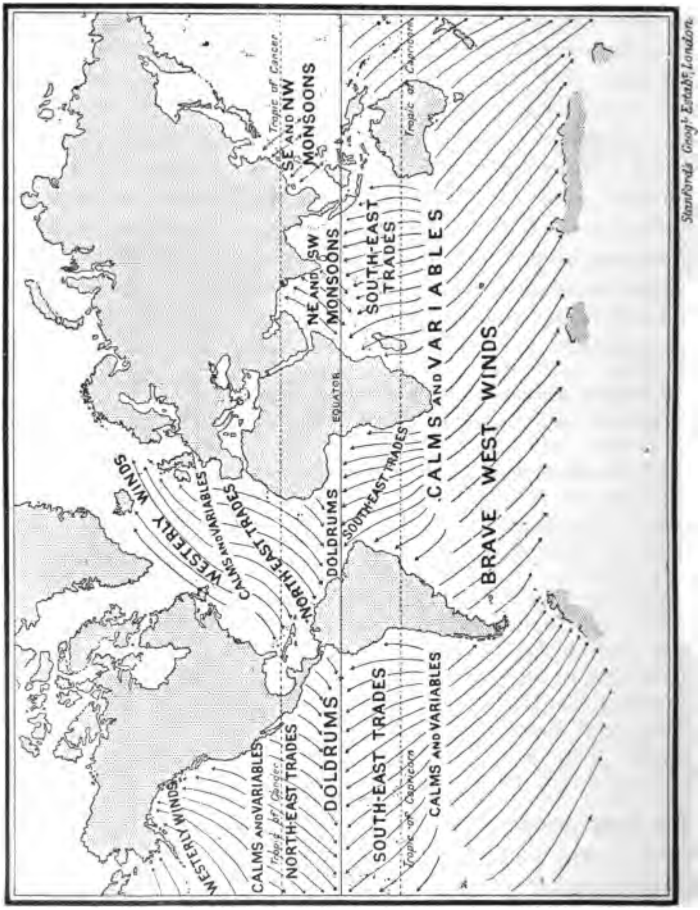


Fig. 105.—The permanent winds of the World.

subjected to two velocities—(1) that which it has in a southerly direction, depending upon the actual pressure-difference between the place from which it starts and that towards which it moves; (2) that which, as a part of the rotating earth, it has from west to

east. But as it travels towards the equator its west to east velocity becomes increasingly less than that of the sea and land beneath it, and its effect on the surface is the same as if it blew from east to west—just as a man travelling in a motor car in the same direction as a wind moving with lower velocity feels the wind blowing in his face. The resultant effect of the two velocities —one actually from the north, and the other relatively from the east—is apparent in the **north-east** winds which are more or less permanent between about lat. 35° N. and the equator. They are known as the **Trade Winds.** They blow with great constancy across the oceans, but are more or less interfered with over the continents, since the local conditions on the land vary considerably from place to place.

By applying the same reasoning to the southern hemisphere it will be clear that the direction of the trade winds south of the equator will be **south-east.**

The trade winds do not blow between the same latitudes in different oceans of the same hemisphere, nor between corresponding latitudes in the two hemispheres. Thus, in the Pacific Ocean the N.E. trades extend over the area between 6° N. and 25° N. latitude, while in the Atlantic they are felt between 7° N. and 35° N.

The south-east trade winds of the southern hemisphere blow between 2° N. and 21° S. latitude in the Pacific, and between 3° N. and 25° S. latitude in the Atlantic Ocean. These limits are not fixed throughout the year, but vary more or less with the seasons.

Prevailing westerly winds.—What becomes of the winds which blow from the high-pressure belts towards the poles? The air moving north-polewards is under the influence of two velocities, one urging it from the south and produced by the pressure-difference existing between the two places; the other tending to make it move from west to east with the rotating earth. The second of these becomes increasingly *greater* than the rotational velocity of the earth beneath, since the wind has come from more equatorial regions with a correspondingly higher rate of speed. For reasons similar to those already given, the resultant velocity will be in an intermediate direction, and the wind will appear to come from the **south-west.** It is these winds in the **northern hemisphere** which

constitute the **prevailing winds in our own country** as well as in others in the same latitudes. A study of the table on p. 345, or of Fig. 212, shows that although local and temporary variations in wind direction exist in our islands, westerly and south-westerly winds predominate in the British Isles at all seasons of the year. Fig. 196 shows diagrammatically the percentage number of winds blowing from various directions at Ramsgate during the year.

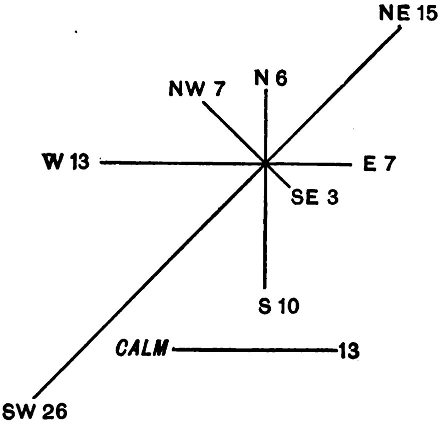


FIG. 196.—"Wind-rose" for the year at Ramsgate. For explanation, see text.

In the southern hemisphere the corresponding winds will manifestly blow from the north-west; they are of much greater importance in these latitudes than in those north of the equator. Their course is across oceans which interfere with their permanent character very little. They are spoken of as the **Brave West Winds**, and the latitudes in which they blow are known as the **Roaring Forties.**

The direction of these winds is contrary to that of the trade winds themselves, and to mark this fact they are sometimes called the **Anti-trades.** This name, however, is often given to those upper currents of air which blow in the atmosphere over the trade winds. These upper winds are the completion of the great convection currents which constitute the winds, for we cannot have a current in one part of a continuous fluid without causing one in other parts.

Circumpolar winds.—The currents of air from the south polar regions, towards the low pressure "trough" which approximately coincides with the Antarctic Circle, are deflected by the rotation of the earth into easterly and south-easterly winds. In the northern hemisphere, the very irregular distribution of land and water areas within the Arctic Circle interferes greatly with the regularity of the pressure distribution and resulting winds, but the general direction of flow is outwards from the pole.

Ferrel's law.—The modification of wind directions by the earth's rotation is merely one example of a general truth sum-

marised in the statement known as **Ferrel's Law**: *If a body moves in any direction on the earth's surface, there is a deflecting force arising from the earth's rotation which tends to deflect it to the right in the northern hemisphere, but to the left in the southern hemisphere.*

Belts of calms.—Zones in which there is little horizontal circulation of the atmosphere occur round the earth in certain latitudes. One of the most marked is the low-pressure belt **just north of the equator** (p. 347). It owes its existence to the high temperature of the earth's surface along this belt, which causes the overlying air to expand and rise, its place being taken by air flowing in from the north and south as the trade winds. Along this belt, therefore, the general direction of the air flow is *vertically upwards*. The resulting belt of calm is marked, amongst other things, by the great rainfall which occurs there. It is often referred to as the **Doldrums**.

Other belts of calms occur in both hemispheres in the regions of lat. 30°–35° and are referred to as the **horse latitudes** or—not very accurately—as the **Calms of Cancer** and **Capricorn** respectively. It is in these latitudes that the *upper* currents corresponding to the trades and to the westerly winds of temperate zones come into contact moving in opposite directions and are mutually compressed. The air naturally *descends* to the surface of the earth, as a result of its increased density, which also raises its temperature and therefore increases its relative dryness (p. 317). It is significant that most of the dry deserts of the earth (p. 376) occur in or near the horse latitudes.

The "calms" should be thought of as places where no permanent winds occur, rather than as districts of absolute rest, for they are subjected to **variable winds** caused by local variations of pressure. The only other similar districts where such calms are prevalent are in the immediate vicinity of the poles, where the earth has little rotational velocity.

Land and sea breezes.—Near the sea, especially in the tropics, there are well-marked breezes, which result from the different heating effect of the sun's rays on land and water. Water has a higher specific heat, and is also a poorer absorber of heat, than land, and consequently during the day the air above the land gets warmer than that above the water, and an upward current of air is set up over the land. The cooler air from over the sea flows in to take the place of the air which rises, and constitutes a **sea breeze**. After sunset both the sea and land begin to radiate their heat; the land, being a better radiator, cools quickly, but the sea remains warm. The air over the water consequently gets

warmer than that over the land, and the pressure above the sea is lower than that over the land, causing a current of air from the land out to sea, which is known as a **land breeze.**

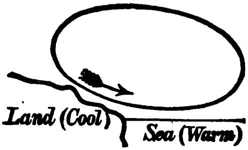


Fig. 197.—Land breeze.

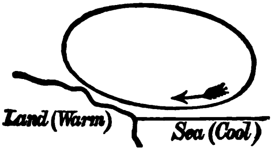


Fig. 198.—Sea breeze.

Monsoons.—In the account of the trade winds no reference was made to the Indian Ocean, because the conditions here change periodically as a result of the nearness of the continent of Asia and of the apparent annual motion of the sun. The name **monsoon** is itself derived from a Malay word meaning a *season*, to mark the fact of the periodical change in the direction of the winds, that is, the seasonal variation which they undergo.

In our summer—as a consequence of the inclination of the earth's axis—the heat equator (p. 298) migrates northward, especially over the great land masses, and the plateaux of Central Asia receive a greater amount of heat from the sun than the waters of the Indian and Pacific Oceans nearer the equator. Since even an equal amount of heat is sufficient to raise the temperature of the land higher than that of the sea (p. 287), it is easily understood that the summer of Central Asia is very hot indeed. The heated air naturally rises because of the decrease in its density, and cooler air from the south and east flows towards the area of low barometric pressure (29·4 inches in Turkestan in July) thus produced.

The north-east trades, which otherwise would blow over the Indian Ocean north of the equator, are entirely overcome and lost in this powerful wind northward; while the south-east trades are drawn across the equator and deflected to the right, in accordance with Ferrel's law (p. 351), to blow over India from May to September as the south-west monsoon. Over low lands this summer monsoon is a dry wind, but where forced into the upper air by encountering the Western Ghats and the Himalayas,

it is cooled by expansion, and deposits its contained moisture as heavy rain.

The trade winds of the Western Pacific also are affected in summer by the low barometric pressure over Central Asia, and are so deflected that they blow over China as a south-east monsoon.

In our winter the heat equator has migrated southward, and the conditions have become reversed. Northern Australia is now a centre of high temperature and low pressure (29·7 inches or less), while Central Asia is a region of excessive cold and high pressure (reaching 30·5 inches in Mongolia). As a consequence the winter monsoon over India blows from the north-east, over southern China from the north, and over northern China and Japan from the north-west. Drawn by the low pressure in Australia, the north-east monsoon blowing over the Indian Ocean is deflected to the left of its course after crossing the equator, and reaches north Australia as the rain-bearing north-west monsoon.

The monsoon effects which occur—to a much smaller extent—in certain other parts of the world (*e.g.* the Guinea coast of Africa, Madagascar, Brazil, and even Spain) are to be explained on similar principles.

Seasonal distribution of pressure.—The distribution of the *permanent* winds has been seen to depend upon the respective positions of permanent high and low pressure belts, which can be studied in a map showing the average distribution of pressure throughout the year (Fig. 199). On the other hand, the *seasonal* variations in wind direction, known as monsoon effects, depend upon seasonal variations in pressure. The extreme limits of pressure variation, like those of temperature variation, are reached in January and July, and therefore maps of January and July isobars (p. 341) are most useful in the study of monsoons.

Such maps show that over the northern continents* the atmospheric pressure is greatest in January, and greater over the land masses (where the temperature is lowest) than over the oceans (which are then warmer than the land). In the southern hemisphere at the same time the conditions are reversed. Further, since the greatest temperature ranges occur over the land, greater seasonal variations in pressure are also experienced by the continents than over the oceans. In addition, such maps of January

* It is remarkable that over the North Atlantic and North Pacific the pressure is greatest in summer.

and July isobars display very clearly the essential constancy of position of those high and low pressure belts which determine the course of the permanent winds.

The following scheme displays the respective directions of the **permanent** or "planetary" **winds**:

Region (approximate).	Pressure.	Direction.	Common Name.
N. Pole - -	High		
	↓	Irregularly outward from North Pole	
Low pressure areas of N. Atlantic and N. Pacific. -	Low	Variable winds	
	↗	Variable W. and S.W. winds	"Westerly variables."
Lat. 35° N. -	High	*Calms* and variable winds	"Horse latitudes."
	↙	N.E. and E. winds	"Trades."
Equatorial Belt	Low	*Calms* and variable winds	"Doldrums."
	↖	S.E. and E. winds	"Trades."
Lat. 30° S. -	High	*Calms* and variable winds	"Horse latitudes."
	↘	Strong W. and N.W. winds	"Brave west winds."
Antarctic Circle	Low		
	↖	S., S.E. and E. winds	
S. Pole - -	High		

The **monsoons** of southern and eastern Asia may be tabulated as follows:

Season.	Neighbouring Region of Highest Pressure.	Neighbouring Region of Lowest Pressure.	Monsoons over Indian Region.	Monsoons over East Indies.
May to Sept.	South Indian Ocean	Turkestan	W. and S.W.	S.E.
Sept. to May	Mongolia	North Australia	N.E.	N. and N.W.

Hurricanes.—Hurricanes and typhoons are often regarded as being those storms which occur in the West Indies and China Seas respectively, but the term is here used in the sense of a **storm**, which may occur in any part of the world. A **hurricane** or **typhoon** may be defined as a large stormy area, often several hundred miles in diameter, within which violent winds circulate round a centre. The centre of a hurricane is a calm region.

A **tornado** is similar in constitution to a hurricane, but much smaller and more violent. If for any reason an area is developed in which the pressure is small, the air round this extent of low

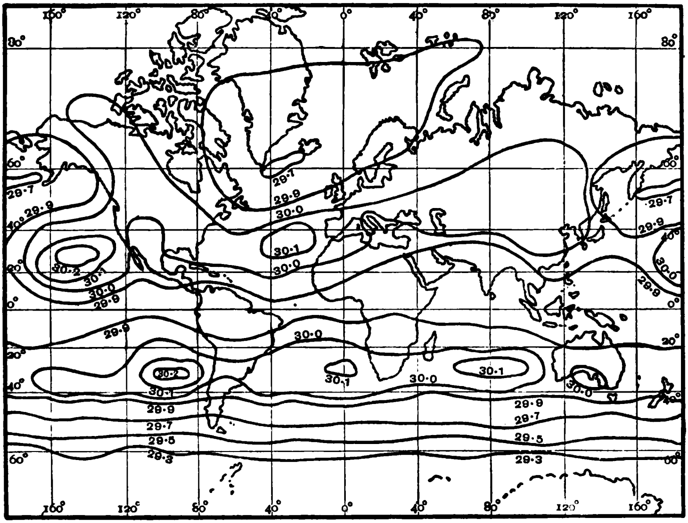


FIG. 199.—The average distribution of atmospheric pressure throughout the year.

pressure will flow in to take its place. The force of the currents inward depends upon the difference of pressure between the air of this area and that outside. Hurricanes and tornadoes—especially those occurring in the Indian Ocean—were formerly called **cyclones**; but the term is now usually restricted to such weather disturbances of temperate regions as will be considered in the next section.

38. CYCLONES AND ANTI-CYCLONES.

1. Isobars.—*An isobar is a line joining places along which the sea level air-pressure is the same.* The corrected height in inches of the barometer at 7 a.m. on June 25, 1909, at the following places was :

La Hève (France)	29·78	Brussels	29·73
Jersey	29·83	Paris	29·86
Frankfurt	29·88	Rochefort	30·00
Belfort	30·03	Munich	30·00

Mark these places and pressures on an outline map of Europe. Draw a straight line joining Paris and Belfort; $30{\cdot}03 - 29{\cdot}86 = 0{\cdot}17$; therefore, at a point A, $\frac{3}{17}$ of the distance from Belfort to Paris, the pressure is probably 30·00. Draw a line through Rochefort, A (estimated), and Munich. This is the 30·0″ isobar. At a point $\frac{4}{17}$ of the distance between Paris and Belfort the pressure is probably 29·9″. Similarly estimate the point between Jersey and Rochefort, and between Frankfurt and Munich where the pressure is 29·9″, and draw the 29·9″ isobar. Put in the 29·8″ isobar in a similar manner.

2. Pressure gradient.—In what direction was the line of greatest pressure-decrease (often called the line of pressure gradient) in that part of Europe at the time? Estimate the pressure gradient in parts of an inch (of barometric height) per 100 miles between Belfort and Brussels. Is the gradient greater or less between Belfort and Brussels than it is between Munich and Frankfurt? The force of the wind at Belfort was 6 (see Beaufort scale on p. 346), and at Munich 3. At which place would you have expected there to be the stronger wind? Why?

3. Behaviour of a low-pressure system in water.—Select a wash-hand basin which empties by a hole at the bottom. One in which the hole is near the centre is to be preferred. Or, better, a large flower pot may be used. Close the hole, fill the vessel with water, and then open the escape. Which part of the surface is highest as the water runs out? Which lowest? Why? Is the pressure of the water greater near the edge or near the centre? Why?

What currents can be detected at the surface? Does the outside water flow in a radial direction towards the centre, or does it describe spiral paths? Is the direction clockwise or anti-clockwise? Repeat the experiment several times to see if there is any constancy in the direction of the spiral when the flow is not interfered with. Can you easily give it any desired direction at the beginning of the flow? How? Make a diagram of the water as seen from above, representing differences of level by contour lines, and direction of flow by arrows. Are the arrows parallel to the contour lines or at a small or large angle? To what extent do these contour lines also indicate varying pressures? Can they be regarded as isobars?

4. Whirlwinds. (*Outdoor work.*)—At the first opportunity make a note of the behaviour of any dry leaves, dust, etc., you may find being whirled round by the wind? In what direction do they move: clockwise or anti-clockwise? Describe any evidence that there is a vertically upward current in the whirlwind. At what part of the ground level of the whirlwind is the pressure lowest? Why do you think so? Does the whirlwind as a whole remain in the same place

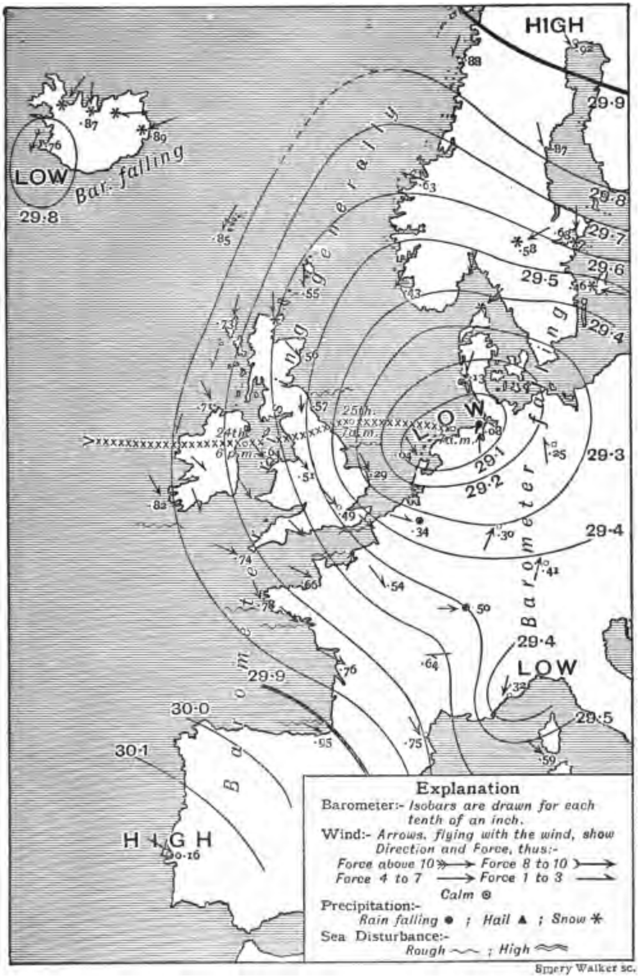


FIG. 200.—A cyclone; map showing the state of the barometer, wind and sea in Western Europe at 7 a.m. on March 26, 1909. (From the *Daily Weather Report.*)

until it collapses, or does it move along? Does it move in the direction of the general wind current, or not?

5. Cyclones.—*A condition of low atmospheric pressure in which the isobars form closed curves is called a cyclone.* Examine Fig. 200.

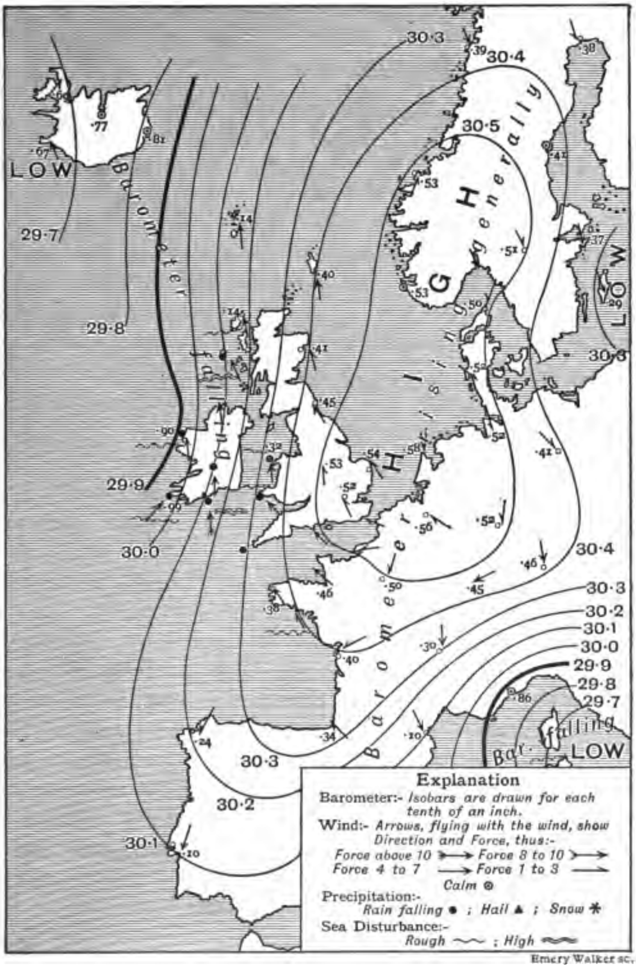
Where, at 7 a.m., March 26, 1909, was the highest barometric pressure in Western Europe? Where was the lowest? What word can be used to describe the depression, of which this latter point was the centre? Why? Where is the pressure gradient greatest, and where least, in the sides of the depression? Do the winds blow on the whole along lines of pressure gradient (*i.e.* across the isobars), or along the isobars? Are they parallel to the isobars, or do they turn inwards or outwards? Is the resulting spiral in the clockwise or anti-clockwise direction? Imagine yourself standing—at any station where a wind arrow is shown—with your back to the wind; is the pressure higher on your left or on your right?

The line of crosses on the map marks the path of the centre of the cyclone (the storm track). State the position of the centre at 6 p.m. on the 24th, at 7 a.m. on the 25th, and at 7 a.m. on the 26th of March? In which direction is it travelling? Estimate its speed. Which countries are respectively in front, in the rear, on the left and on the right of the moving cyclone? What are the wind directions in front, in the rear, on the right and on the left of the cyclone on the map? Account for the following wind directions in two stations respectively north and south of the path of the cyclone:

Station.		March 24.		March 25.		March 26.
		Morning.	Evening.	Morning.	Evening.	Morning.
Leith	Wind	S.E.	E.N.E.	N.N.E.	N.N.W.	N.W.
	Bar.	29·63	29·29	29·11	29·38	29·59
Nottingham	Wind	S.	S.W.	W.	N.N.W.	N.W.
	Bar.	29·75	29·34	29·10	29·22	29·51

What information of the approaching cyclone might have been obtained at Leith and Nottingham from the change in wind direction?

What changes in wind direction do you suppose have taken place at stations on the "storm-track"? Examine Fig. 177, and say whether the winds of the cyclone are likely to be colder on its eastern or its western side. What changes of *temperature* are likely, in general, to precede and follow a cyclone? What are the wind directions at stations where (*a*) snow, (*b*) rain is shown to be falling? What pressure changes will follow the changes of temperature (p. 341)? How is the barometric pressure altering, (*a*) on the east (*b*) on the west of this cyclone? Will such pressure changes tend to make this cyclone travel eastward or westward?



Emery Walker sc.

FIG. 201.—An anti-cyclone; map showing the state of barometer, wind and sea in Western Europe at 7 a.m., April 3, 1909. (From the *Daily Weather Report.*)

How does the path of the cyclone agree with the direction of the prevailing winds of Western Europe?

6. Anti-cyclones.—*An anti-cyclone is a condition of high atmospheric pressure in which the isobars form closed curves.* What is the highest

pressure marked on Fig. 201? Where is it situated? Where is the pressure gradient greatest? What is its direction? Imagine yourself standing—at any station where a wind arrow is shown—with your back to the wind; is the region of high pressure on your right or on your left? Combine this with the result of the similar observation in Ex. 5 above, and formulate a rule which is equally applicable to cyclones and anti-cyclones. Is the circulation of the winds in an anti-cyclone clockwise or anti-clockwise?

Weather charts.—With a view of ascertaining the conditions upon which the various types of weather depend, and therefore of discovering means of making weather forecasts, it has become customary to record the atmospheric changes which occur at the different observing stations scattered over the various countries of the civilised world. These observations are recorded in different ways in the form of **weather charts.**

In our country the most complete and valuable daily charts are those contained in the **Daily Weather Report** issued by the Meteorological Office. The report includes such observations as those of the pressure, temperature and hygrometric state of the atmosphere; the rainfall, the amount of bright sunshine, condition of the sky, the direction of the wind, and so on. A system of letters and symbols of fairly general application has grown up; and a list of some of these has been given on p. 344. A "synoptic" chart of Western Europe—showing the state of the barometer, the direction and force of the wind, the sea disturbance, the temperature of the air (by means of isotherms), the normal temperature of the sea for the current month (by means of a scale of tints), as well as areas under rainfall and notes of the weather generally—are given in each report. Other information supplied by the sheet consists of supplementary charts of "Barometer, wind and weather for 7 a.m. and 6 p.m. yesterday," tables of the reports received from the various observation-stations, and from ships at sea (by wireless telegraph), notes on the weather of the same morning and previous day, a "general inference from the 7 a.m. observations," and a forecast of the following day's weather for each of the eleven districts into which the British Isles are divided for the purpose.

Another admirable chart, supplying much of the information

just referred to, is contained in *The Times* newspaper every morning.

Isobars.—In the preparation of such weather charts the corrected barometer readings telegraphed every morning to the Meteorological Office in London are marked upon the map, at the points representing the positions of the 69 stations in Western

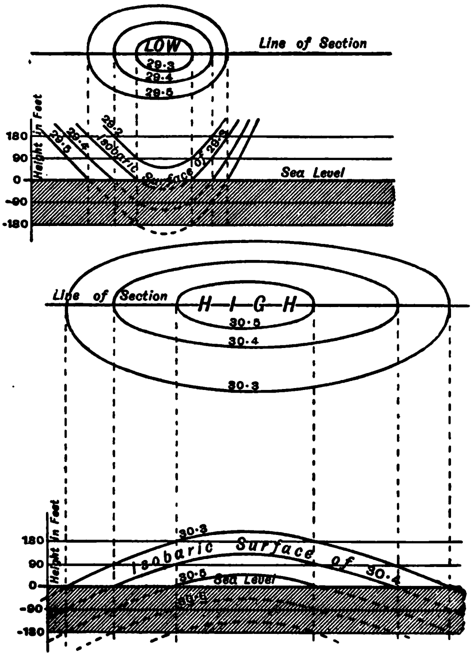


FIG. 202.—Isobars and isobaric surfaces of a cyclone (upper figure) and an anticyclone (lower figure).

Europe from which they are usually received, in the manner shown in Figs. 200 and 201. Lines are then drawn joining those places where the pressure is the same, and these lines of equal pressure, called **isobars**, are shown with the corrected reading of the barometer appended to them.

These isobars are of the greatest value in enabling the meteorologist to study the distribution of atmospheric pressure over large

areas. They are filled in for differences of one-tenth of an inch in the barometric reading. If a line be drawn such that it is perpendicular to every isobar through which it passes, it will represent the direction in which the pressure is altering, or the line of **pressure gradient.** It is clear that the gradient is greatest where the isobars are closest, and it is here, naturally, that the force of the wind is usually greatest. The "steepness" of the barometric gradient may be expressed by the difference in pressure for a given unit of distance measured along the line of gradient.

Isobaric surfaces.—An isobaric surface is one which passes through points having the same atmospheric pressure. It cuts the sea level along the lines called isobars. The isobaric surface of 29·9 inches (*e.g.*) reaches sea level along the isobar of 29·9 inches, but is above sea level where the sea-level pressure is more than 29·9 inches. In regions of high pressure, therefore, the isobaric surfaces are dome shaped; in regions of low pressure they are basin shaped, as will be clear from Fig. 202.

Movements of the air in cyclones and anti-cyclones.—A wind always blows from a place where the pressure is high to one where it is lower, and the force of such a wind depends upon the rate of the difference in pressure between the two places, that is to say upon the barometric gradient. Moreover, a study of the direction of the wind side by side with the distribution of the isobars reveals the fact that the wind moves along lines which are nearly coincident with the isobars, but which tend to cross from the higher to the lower ones. It soon becomes evident, if the isobars are drawn regularly for consecutive diurnal observations of pressure, that the isobars often take the form of *closed curves* which include **an area of low barometric pressure.** Consequently, from what has been just remarked about the direction of the winds compared with the isobaric lines, it follows that the winds are also moving in curves roughly coincident with the lines of equal pressure. Such a condition of things (Fig. 200), where a district of low pressure is surrounded by zones of higher pressure, constitutes what is known as a **cyclone** or **depression**; or in America as a *low*. The curved path which the wind follows in such a cyclone is really a left-handed spiral which results from the rotation of the earth affecting what might otherwise be a simple radial motion of the wind towards the centre of the low-pressure area. Though this **anti-clockwise** motion characterises the cyclones in the northern hemisphere, the direction is clockwise in the southern hemisphere.

The ultimate result of cyclonic movements is the formation of an upward current of air above the central low-pressure area, with the consequent tendency for air to flow from the regions around to take its place. The ascending air in the middle of a cyclone—as elsewhere—expands as its pressure decreases. The expansion is accompanied by cooling which causes condensation of its moisture in the form of **rain**, sleet or snow (Fig. 200). The wind in the centre of a cyclone is generally very slight.

The form assumed by the isobars at some periods of observation reveal a condition of things exactly opposite to that in a cyclone, viz., a **high-pressure area** surrounded by belts of lower and lower barometric pressures (Fig. 201). Such a phenomenon constitutes an **anti-cyclone**. In anti-cyclones in the northern hemisphere the air movements take the form of right-handed outward moving spirals, or, in other words, the winds move in a **clockwise** manner. It has been found, too, that the winds are generally stronger in cyclones than in anti-cyclones.

The anti-clockwise movement of the winds of a cyclone, and the clockwise direction of those of an anti-cyclone are both conveniently expressed in **Buys Ballot's Law**: *In the northern hemisphere a person standing with his back to the wind has the lower pressure on his left hand.* The law indeed applies to winds generally. It is plain that as a cyclone travels along the earth's surface, the winds at places affected by it must change in direction to assume their appropriate relation to the shifting area of low pressure. Indeed a change in the direction of the wind at a place often heralds the approach of a cyclone before the barometer has begun to fall.

The average height of a cyclone is only about 6 miles, but its superficial extent is sometimes very great, reaching in some cases a thousand miles across; there is always a tendency for such extensive cyclones to subdivide into smaller ones. Usually one of the subdivisions is a cyclone of greater intensity than the others, and its intensity generally increases gradually to a maximum, while the others disappear. Another point of interest is that the cyclone is often drawn out, as it were, in one direction, making its form oval, with the longer diameter at least half as great again as the shorter.

The rate of advance of a cyclone varies within very wide limits. The centre of a cyclone which at 6 p.m. on March 24th, 1909, was half way between Ireland and the Isle of Man, had only reached the north coast of Holland by 7 a.m. on March 26th (Fig. 200). On the other hand, a cyclone which was off the west coast of Ireland at 7 a.m. on April 29th had reached a position south of Denmark 24 hours later—a much more rapid rate of progress. "Van Bebber

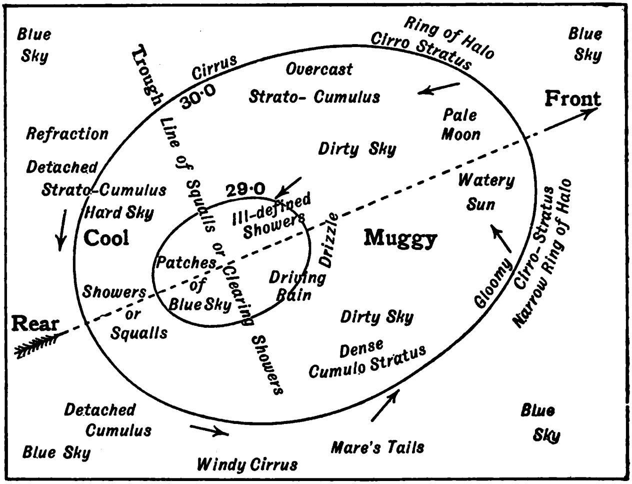


FIG. 203.—Weather conditions accompanying a cyclone (Abercromby and Marriott).

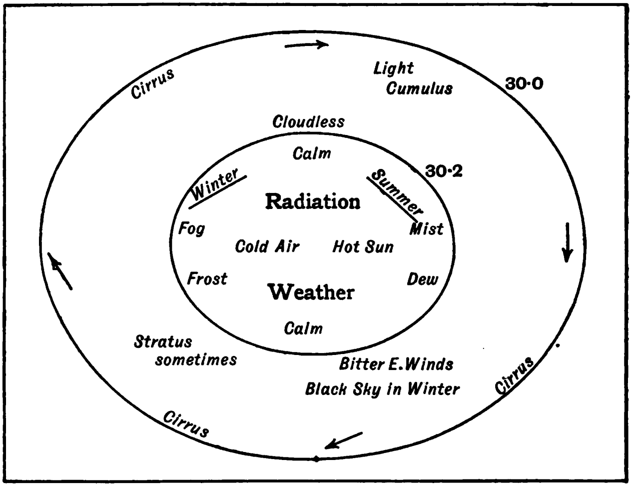


FIG. 204.—Weather conditions accompanying an anti-cyclone (Abercromby and Marriott).

gives, as the average of 1,676 cases, a mean velocity of 27 kilometres per hour, the highest average occurring in October (31 km.), the lowest in August (23 km.)."*

It is said that on the average the weather of western Europe is under the influence of cyclones for more than 100 days in every year.†

Weather forecasting.—In middle temperate zones, where the prevalent winds are westerly, the areas of low or high pressure, as the case may be, move **from west to east** along certain more or less well defined tracks. The weather to be expected with the various types of cyclones and anti-cyclones is known (Figs. 203 and 204) from past observations; so that regular telegraphic information of the barometric and other conditions prevailing, especially to the westward, enables the Meteorological Offices of America and Europe to issue forecasts for two or three days ahead, which in a large majority of cases prove substantially accurate.

In the torrid zone, where there are north-east trade winds in the northern, and south-east winds in the southern hemisphere, blowing with great regularity, there are comparatively few cyclonic disturbances.

Comparison of cyclones and anti-cyclones.‡—

CYCLONES.	ANTI-CYCLONES.
Winds.	
1. Strong in force; at times severe gale, or hurricane.	1. Light in force, often calm.
2. In the northern hemisphere circulate left-handed round the centre of the system.	2. In the northern hemisphere circulate right-handed round the centre of the system.
3. Draw in spirally *towards* the centre.	3. Draw out *from* the centre towards the neighbouring cyclones.
Temperature.	
1. Low in summer.	1. High in summer.
2. High in winter.	2. Low in winter.

* Dickson's *Meteorology*, p. 71.

† See E. Gold's articles on "The Construction and Reading of Weather Maps."—*School World*, July, August and September, 1909.

‡ Gaster, *Q.J. Roy. Met. Soc.*, July 1896.

Cyclones.	Anti-cyclones.
Weather.	
1. Rough and squally.	1. Quiet and dry.
2. Rain in summer, snow in winter, thunderstorms in both seasons, but especially in summer.	2. Cloudless and bright in summer, with haze at times; foggy or bright in winter.

The characteristic weather accompanying cyclones and anti-cyclones respectively is shown in more detail in Figs. 203 and 204.

The terms "cyclone" and "anti-cyclone" do not describe phenomena that can be observed by one observer or at a single station; they should, therefore, not be used in the description of local phenomena; they represent generalisations based upon the charting and study of winds and clouds observed at many stations, and should only be used when the nature of the rotation of the winds has been clearly demonstrated or can be safely inferred.

Recent researches show that the condition of things in the cyclone and anti-cyclone is not so simple as has been supposed. Many of the views which have been hitherto received are being modified, as the student who wishes to pursue the subject further will find by referring to Dr. W. N. Shaw's *Forecasting Weather* (Constable). Especially is this the case so far as anti-cyclones are concerned. Dr. Shaw points out that these "are not of single meteorological character. Local changes of many kinds may take place within them, and almost any kind of weather, except those which represent violent atmospheric changes, may be associated with their central regions."

EXERCISES ON CHAPTER XIV.

1. Explain the wind systems of the Equatorial Regions, showing the effect of heated land masses upon direction. Illustrate your answer by reference to South India and Ceylon, Nigeria, British East Africa and British Guiana. (P.T.)

2. Draw a map to show isobars and winds in a low-pressure system (cyclone) the centre of which (29 inches) is over the heart of England, while the pressure in Kerry is 29·7 inches, in Caithness 29·9 inches and in Dover 29·5 inches. If it is moving due eastwards, explain the changes of wind during the next twenty-four hours at Dover. (C.P.)

3. What is a monsoon wind? Explain the south-west monsoon of India. Draw a sketch-map to show to what parts of India it brings rain. (L.J.S.)

4. Explain fully how the direction of the trade winds is influenced by the Earth's rotation. (O.S.)

5. What is atmospheric pressure, how is it measured, and how shown on maps? Contrast the distribution of pressure over Eurasia in summer and winter respectively.

6. What are monsoon winds? Where, when, and from what directions do they blow? What parts of Asia receive rain from monsoon winds? (L.J.S.)

7. What are isobars, and how are they drawn on maps? Explain how by means of a map on which these lines are drawn we can approximately estimate the force and direction of the wind. Why is it preferable to have isobars drawn for January and July than for the whole year? (C.P.)

8. What is meant by a monsoon wind? Describe in particular the conditions of temperature, pressure and rainfall during the summer monsoons in the Indian area.

9. Describe as fully as you can the monsoon winds of S.E. Asia and their causes. (L.C.C.)

10. How are storms predicted in the British Isles? Illustrate by means of a diagram or chart. (L.J.S.)

11. What is meant by pressure of the atmosphere? How is it measured, and how described? (C.J.)

12. Where are the trade winds met with, and how are they caused? How is the direction of a wind defined? (C.J.)

13. Point out the connection between areas of high and of low pressure and the direction of the wind. What influence has the rotation of the earth on winds? In what direction do winds blow that are most altered in direction thereby? (C.P.)

14. Give a description of the monsoons of the Indian Ocean and their influence on the ocean currents. (C.J.)

15. Describe and account for the belt-like arrangement of winds and calms over the Earth. (J.B.M.)

16. On the accompanying map the barometric pressures (reduced to 32° F. and to sea level), at 8 a.m. on 19th October, 1906, are shown at the points marked.* Draw isobars and indicate the direction of the

* The points and pressures were: Bodo 29.86, Haparanda 29.96, Christiansund 30.09, Hernösand 30.13, Sumburgh Head 29.96, Stornoway 29.92, Wick 29.87, Skudesnaes 29.93, Karlstad 30.07, Stockholm 30.06, Skagen 29.93, Fanö 29.83, Cuxhaven 29.84, Berlin 29.99, Frankfurt 29.95, Brussels 29.80, Flushing 29.70, Paris 29.87, Rochefort 29.95, Biarritz 29.97, Brest 29.84, Munich 30.08, Lyons 30.03, Perpignan 30.01, Nice 30.08, Aberdeen 29.73, Leith 29.70, N. Shields 29.42, Nottingham 29.62, Yarmouth 29.60, London 29.73, Scilly 29.83, Pembroke 29.77, Holyhead 29.73, Liverpool 29.67, Malin Head 29.79, Blacksod Pt. 29.83, Valencia 29.81.

winds by means of arrows. Describe the general character of the weather in England at the time when the observations were made. The map is to be returned with your answers. (C.S.)

17. Draw or write a brief description of a weather map of a low-pressure system or cyclone, the centre of which is at London, where there is a pressure of 29·0 inches, while 600 miles in all directions the pressure is 30·0 inches. (L.J.S.)

18. How does the height of a barometer vary as a cyclone passes over it?

19. What is an anti-cyclone? Describe the weather which is experienced in an anti-cyclone.

20. What are isothermal and isobaric lines? How do the directions of each alter in the Northern Hemisphere as we pass from winter to summer, and why? (C.P.)

21. What are *monsoons?* Give their limits in Asia. Explain how they are formed, pointing out how the rotation of the Earth affects them. Describe the kind of weather found at the changes of the monsoons in any part of Asia. (C.P.)

22. Describe a method of making a barometer. What advantage is there in using mercury as the liquid? Can any other be used? What is the approximate height of a mountain if a barometer on its summit stands at 27 inches when one at the sea level marks 30 inches? (C.P.)

23. Sailing ships go from England to New Zealand by the Cape of Good Hope, but return from New Zealand to England by Cape Horn. What are the geographical reasons which account for this difference in the outward and homeward routes? (O.J.)

24. Explain the distribution of pressure, winds, and weather in an anti-cyclone. Under what conditions does a lasting high-pressure area form over Eurasia? (J.B.M.)

25. Explain how weather forecasts are made. (J.B.M.)

26. What weather is to be expected:

(*a*) When the wind is backing from the westward to the southward and the barometer has begun to fall?

(*b*) When the wind is veering from southward to westward and the barometer has begun to rise?

(*c*) When the wind is backing from south to east and the barometer is falling?

(*d*) When the wind veers from north to east and the barometer is falling?

CHAPTER XV.

CLIMATE.

39. THE CLASSIFICATION OF CLIMATES.

1. Sunshine zones.—What are the limits of latitude in which the sun is

(*a*) sometimes vertically overhead ;

(*b*) never overhead, yet rising and setting every day ;

(*c*) sometimes above, and sometimes below, the horizon for more than 24 hours at a time?

How are these zones named in your atlas?

2. Wind zones.—Make a table showing approximately the limits of latitude in which prevail

(*a*) the trade winds ;

(*b*) the "westerlies" ; and

(*c*) the doldrums respectively (p. 351), and compare the zones with the sunshine zones. Shade the wind zones on an outline map of the world.

3. Supan's temperature zones.—Examine Fig. 206. Describe in words the course of the mean annual isotherms of 68° F., and of the isotherms of 50° F. for the warmest months of the northern and southern hemispheres. How do the belts thus marked correspond with the sunshine and wind belts? How do you explain the widening of the hot belt over the continents, and the greater width of the north "temperate" belt than the southern?

Climate.—By the word climate is meant the average condition of the weather. We have learnt that variations in the weather are chiefly due to the influence which changing **temperature** has upon atmospheric **moisture** and upon the movements of the air.

Sunshine Zones.—Since the surface of the earth receives its heat from the rays of the sun, it was natural that the earlier systems of classifying climate should be based largely upon the amount of daylight which different parts of our planet receive throughout the year. The commonest of such systems is that in which the earth's surface is divided (Fig. 205) into

FIG. 205.—The sunshine zones.

(1) a **torrid** or tropical zone lying between the tropics of Cancer and Capricorn, *i.e.* between lat. 23½° N. and 23½° S.;

(2) two **temperate** zones, lying between the tropic of Cancer and lat. 66½° N., and between the tropic of Capricorn and lat. 66½° S.; and

(3) the two **polar**, or "frigid" zones or "caps."

The torrid zone, in other words, is the zone including all places over which the sun is vertical twice in the year (p. 95); in the temperate zones the sun's rays are never vertical, but the sun rises and sets once in every 24 hours; in the polar zones the days and nights are sometimes more than 24 hours long.

It is clear that on this classification countries having very dissimilar climates are included in the same belt, since it takes no account either of many of the circumstances modifying temperature, or of the influence of prevailing winds.

Wind zones.—The suggestion by Prof. W. M. Davis * that the great wind belts of the world be taken as the basis of a classification of climate has many points in its favour. Climate is dependent to a very great extent upon rainfall, which in its turn is controlled by the relative humidity and direction of the prevailing winds. According to this scheme, the "tropical" zone includes the equatorial belt of calms, and the regions over which the trade winds blow; the "temperate" zones similarly fall in the latitudes

* Prof. Davis described these wind belts in an article in *The School World*, July, 1899.

affected by the westerlies. Not only, however, are the boundaries of the wind belts somewhat indefinite at all times, but they shift according to the seasons.

Thus, countries on the polar margins of the trade-wind belts lie sometimes in the tropical and sometimes in the temperate zones, as thus defined. Again, a classification based entirely on prevailing winds would include in the temperate zones certain

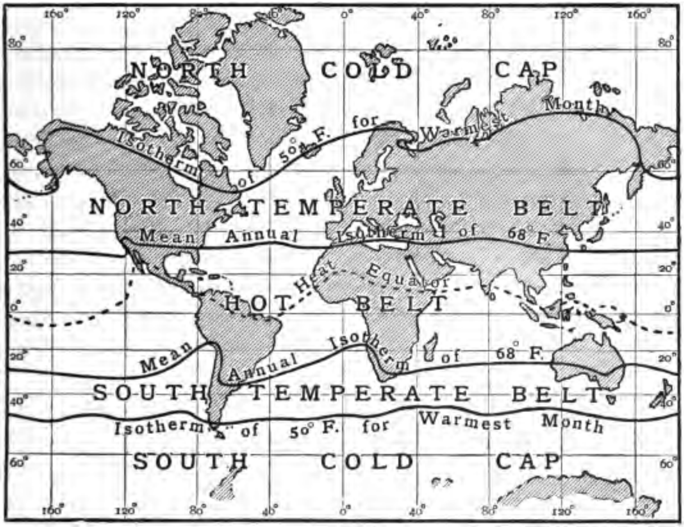


FIG. 206.—Supan's temperature zones.

ill-defined regions falling within the Arctic and Antarctic circles, and having climates in no real sense temperate.

Temperature zones.—On the whole, perhaps the most generally satisfactory classification of climatic zones yet proposed is that due to Supan (Fig. 206). In it the **Hot Belt** is bounded by the two mean annual isotherms of 68° F., "a temperature which approximately coincides with the polar limit of the trade winds and with the polar limit of palms. The latter is considered by Grisebach to be the truest expression of a tropical climate. . . . The polar limits of the **temperate** zones are fixed by the isotherm of 50° F. for the warmest month. . . . Summer heat is more important

for vegetation than winter cold; and where the warmest month has a temperature below 50° F., cereals and forest trees do not grow, and man has to adjust himself to the conditions in a very special way." * It has been pointed out that the great extremes of temperature and humidity, to which places in these zones are subject throughout the year, make the term "temperate" very unsuitable. They would be described more accurately as **intermediate** zones. Also the northern and southern caps are better called **polar** than frigid.

Types of Climate.—In each of the climatic zones thus defined there exists great variety of climatic conditions, due largely to proximity or otherwise to the ocean, to the direction of prevailing winds, and to varying altitude of the land. It is therefore necessary to recognise in each zone a distinction between the marine or **oceanic** type and the **continental** type of climate; with the intermediate variety known as the **littoral** (shore), and the extreme continental conditions of the **desert**, climates. Among continental types **mountain** and **plateau** climates will also be included. In regard to temperature, the chief differences between these conditions have already been considered (Chapter XII.). They may be conveniently summarised here.

Marine or oceanic climate.—Water is warmed and cooled much more slowly than the land, and to a smaller extent for a given exposure to sunshine. Hence an oceanic climate is one with only a slight difference in summer and winter (Fig. 176) and in day and night temperatures. The copious evaporation keeps the air moist, favours cloudiness, and causes an abundant rainfall in the colder months.

The **littoral** or coast climate in general resembles the oceanic type, especially where the prevailing winds blow from the sea. Where the prevailing winds are in the opposite direction the coasts have naturally a climate approaching the continental type.

The continental climate.—The temperature of the land rises more quickly and to a greater extent than that of water in summer; conversely, it falls more quickly and to a greater extent in winter. Continental climates, therefore, show a large annual *range* of temperature, which is greater in general as the distance

* *Climate* by R. de C. Ward (Murray).

from the sea increases (Fig. 176). Further, the springs are warmer and the autumns cooler than in marine climates. The relative humidity and cloudiness of the atmosphere are less, and rainfall in general decreases, with distance from the sea; although both the amount and frequency of rainfall depend considerably upon the prevailing winds and the elevation of the land.

Mountain and plateau climates differ from those of the lowlands in all parts of the world,

(1) in the lower pressure and temperature of the air;

(2) in their freer exposure to solar light and heat, and at the same time, the more rapid cooling of their land surface, giving rise to greater *ranges* of temperature;

(3) in their generally more abundant rainfall.

Mountain ranges often act as barriers, or *climatic divides*, separating regions of very different weather conditions. In this connection the fact that $\frac{9}{10}$ of the water vapour in the atmosphere is below 21,000 feet is significant.

The differences, in regard to temperature, of the principal types of climate, are clearly shown in the following table: *

Zone.	Place.	Type of Climate.	Lat.	Mean Temp. of coldest month.	Mean Temp. of warmest month.	Range of Temperature.
Tropical	Wady-Halfa	Continental	21° 53′N.	61·3° F.	93·4° F.	32·1° F.
	Honolulu	Marine	21° 18′N.	70°	77·5°	7·5°
Sub-Tropical	Bagdad	Continental	33° 19′N.	50·9°	92·8°	41·9°
	Bermuda	Marine	32° 20′N.	61·7°	80·1°	18·4°
Temperate	Semi-polatinsk	Continental (Lowland)	50° 24′N.	0·5°	72°	71·5°
	Kiakhta (Mongolia)	Continental (Plateau)	50° 21′N.	−15·9°	66·4°	82·3°
	Scilly Is.	Marine (W. Coast)	49° 55′N.	45·7°	61·2°	15·5°
	Saghalien Is.	Marine (East Coast)	50° 50′N.	−0·4°	62·2°	62·6°

* Compiled from statistics given in Ward's *Climate* (Murray).

The desert climate is an extreme type of the continental climate, showing an even greater contrast between the temperatures of day and night and of summer and winter. This accounts very largely (p. 223) for the extensive splitting and destruction of rock masses, and the abundance of sand; and the high winds (which are as characteristic of deserts as they are of oceans) complete the erosion of the rocks by the scouring action of driven sand.

40. THE TROPICAL ZONE.

1. The climates of the trade winds.—On an outline map of the world mark the great mountain chains and plateaux, and colour *blue* that side (called the windward side) of each on which the trade winds blow (*a*) from the sea or (*b*) from a warmer to a colder region.

Are such winds likely to bring rainy or dry weather? Is the windward or the leeward (sheltered) side of a range of hills, exposed to a damp wind, likely to have the drier climate?

Colour *yellow* (*a*) the leeward sides of such hills, and (*b*) areas exposed to trade winds blowing from continents, or from colder to warmer regions.

For the present, leave uncoloured the southern and eastern coasts of Asia, the shores of the Gulf of Guinea, and Equatorial Africa.

2. Monsoon climates.—Revise the account of the migration of the heat equator (p. 298) and of its effect upon the direction of the monsoons (p. 352). In which season of the year are the various monsoons rain-bringing and drying winds respectively? Why?

Colour appropriately (by alternate blue and yellow strokes) the regions affected by monsoons.

3. The belt of equatorial calms.—In the doldrums (p. 351) there are usually daily (*afternoon*) rains. Are the doldrums stationary, or do they shift with the migration of the heat equator? What countries do you suppose lie in the doldrums for part of the year and in a trade-wind zone for the rest? What tropical countries do you suppose have *in consequence* both dry and rainy seasons? Explain why. Are the various rainy seasons probable in our summer or in our winter?

Shade such countries as these on your map with black lines over the blue or yellow.

The tropical zone.—The climate of the "hot belt" of the earth—bounded by the mean annual isotherms of 68° F.—is, in its

main features, remarkably uniform; and any variations of weather which do occur, appear at regular intervals—occasional tropical

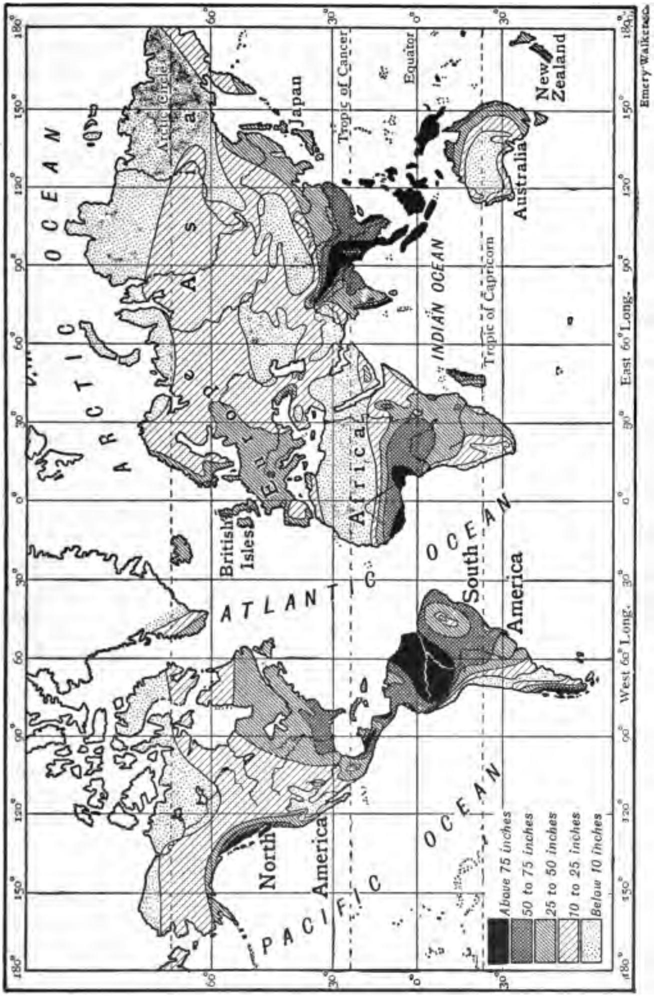


FIG. 207.—Rainfall map of the world.

cyclones (p. 355) forming almost the only exception to the rule. The extent of the water surface in this zone greatly predominates

over that of the land surface, so that the climate is on the whole "oceanic" in character (p. 372) with a typically small mean annual range (from 5° to 10° F.) of temperature (Fig. 176). Indeed, the differences between mean day and night temperatures are in most places—deserts excepted—larger than the mean annual range; and seasons, in the ordinary sense of the word, do not exist. Variations in climatic conditions in the tropics are thus dependent upon the prevailing winds and rainfall.

The trade-wind belts.—Over the greater part of the tropical zone the **trade winds** blow with great regularity throughout the year. It has been learnt (p. 349) that these winds come from the north-east and south-east to regions of lower latitude, *i.e.* from relatively cooler to relatively warmer regions. So long as their course is over the sea or over low-lying land, therefore—and especially near their origin in the high pressure belts (p. 351)—the trade winds are dry. On the other hand, when they strike mountains they rise, are chilled by expansion, and the abundant moisture they contain is precipitated as rain. In general terms, then, it may be said that the **eastern slopes** of high lands in the trade-wind belts have a heavy rainfall and luxuriant tree growth; low-lying land and the *western slopes* are relatively *dry*, and may even exhibit the "desert" type of climate. To these facts may be attributed the contrasts (Fig. 207) between the heavily watered east coasts and the much drier west coasts of Central America, the West Indies, the East Indies and Eastern Archipelago, Madagascar, Ceylon, etc. As for the continents of the zone, the coast of Guiana and south-eastern Brazil have a heavy rainfall, while the Pacific coast of South America (on the leeward side of the Andes) is a rainless desert from the equator to lat. 30° S., and another markedly arid region lies between the Brazilian Highlands and the Selvas of the Amazon.

Again, the rainfall map shows a striking contrast between the well-watered east coast of Australia and the **desert interior** from which the eastern highlands separate it; and also between the south-eastern coast of Africa and the dry land to the leeward side of the mountain barrier. The cold ocean currents bathing the western coasts of South America and South Africa (Fig. 154) accentuate the inhospitality of these desert regions (Fig. 207). On such windward coasts and mountain slopes as those just described, where the rainfall is entirely derived from the trade winds, the "winter" is wetter than the "summer," since the trades blow with greater force in winter.

The trade winds of Northern Africa are not, in the first place, heavily laden with moisture, since they have not recently blown over the ocean; and, secondly, since their direction is from higher

to lower (*i.e.* from cooler to warmer) latitudes over flat country, their relative humidity is becoming increasingly less. As a consequence, the greater part of Northern Africa is occupied by the desert of Sahara, with the characters of climate already described on p. 374. The conditions in Arabia north of the twentieth parallel of latitude are very much the same as those of the Sahara, and have resulted similarly in the formation of a desert.

FIG. 208.—The Sind Desert. (*Survey of India*, 1900-1.)

The equatorial belt.—It has been learnt (p. 351) that the **doldrums** are regions of calms between the north-east and south-east trades. In the doldrums, the moisture which is evaporated during the hottest parts of the day is carried rapidly upwards, cooled by expansion, and condensed, so that daily rains fall in the afternoons and evenings. Since, however, the "belt of daily rains" follows the migration of the heat equator, it shifts a little to the north in our summer and a little to the south in our winter. It follows that places which lie in the doldrums, and have daily rains, at one time of the year may be in the trade-wind belt, and have little or no rain, at another. The resulting division of the year into **dry and rainy seasons** is naturally most marked near the extreme north and south limits of the annual migration of the

doldrums, but in some regions—*e.g.* to the east of the Andes—it is not well marked. The wet season is naturally most prolonged nearest the equator; and in parts of Central Africa and in the basin of the Amazon, for example, abundant rain falls at all seasons of the year, favouring the growth of dense forests.

Monsoon regions.—It has been explained in Chapter XIV. that monsoon winds (which change with the season) are, like the alternating land and sea breezes of night and day, due to the unequal warming of land and sea, and blow, in general, from cooler to warmer regions. For this reason monsoons are drying winds unless they are cooled by local circumstances, as when they encounter high mountains; in that case they bring heavy rain. The rainfall of Cherra Punji, on the southern slopes of the Himalayas, for example, is the heaviest known (464 in.): it is to be attributed to the south-western monsoon of the summer (May to September), which is sufficiently strong to overcome the north-east trades between lat. 10° N. and the Tropic of Cancer, or slightly beyond this, from East Africa to China. Wherever these winds strike the high lands of southern Asia and the East Indies, they similarly cause rain. In the northern winter, on the other hand, the monsoon winds of the same regions blow from the north, and reach northern Australia and the neighbouring islands as north-westerly rainy winds.

Southern Asia and the East Indies furnish the most conspicuous illustrations of climatic control by monsoons, but other examples are to be found in the Gulf of Guinea, and even in Spain.

41. THE TEMPERATE ZONES.

1. The influence of winds upon rainfall.—To what extent do the "temperate" zones in Supan's classification correspond with the areas over which the westerlies blow? Do these winds come, in general, from warmer to cooler regions, or the reverse? Are they, as a consequence of this, likely to bring rainy or dry weather to (*a*) windward, (*b*) leeward coasts?

On your outline map mark in blue the coasts and slopes likely to be rainy, and in yellow those likely to be dry, on this account.

2. Annual range of temperature.—Examine Fig. 176. What evidence does it give that the north "temperate" zone is inappropriately named? Can you trace any connection between extent of temperature range and the character of the prevailing winds? Compare in this respect British Columbia, Labrador, England, and Kamchatka. Do ocean currents affect the facts materially?

Find out from Figs. 174 and 175 whether the summers are cooler in the north or in the south temperate zone.

3. Sub-tropical belts.—Bearing in mind the shifting of the trade-wind zone with the seasons, on what west coasts would you expect *dry summers and mild rainy winters*? What rainfall conditions would you expect in the Mediterranean region? Why? In what sense could California be expected to have the **Mediterranean type of climate?** Mention places in the southern hemisphere which seem likely to have a similar climate. Why cannot the Mediterranean type of climate be expected in Florida, in Japan, and on the east coasts of South Africa and Australia?

How would you expect the seasonal distribution of rainfall to differ in Western Europe northward from the Mediterranean? What effect has this on the directions of winter and summer isotherms (p. 298)?

4. The climate of the British Isles.—What are the prevailing winds of the British Isles?

(*a*) *Rainfall.*—Examine Fig. 214 side by side with an orographical map of the British Isles. What and where is the greatest mean annual rainfall shown? What and where is the least? Which are the wettest and which the driest counties? Have hilly or flat districts a greater rainfall? Mention ten pairs of towns, on opposite sides of high land, which have marked differences in rainfall. Is the rainfall greater generally on the west, or on the east, side of hills and mountains? Is this the windward or the leeward side? Can you find any exceptions?

(*b*) *Temperature.*—Revise the exercises (**32**, 4, p. 294) on the distribution of temperatures in the British Isles.

The temperate zones.—The so-called temperate zones—as defined by temperature—are included in each hemisphere between the mean annual isotherm of 68° F. and the isotherm of 50° F. for the warmest month. These zones comprise, broadly, the areas over which the westerlies (p. 349) blow. It will be remembered that these winds blow in general from lower to higher latitudes; they are therefore cooling continuously, and tend to cause mild rainy weather on the eastern shores of the oceans.

The oceanic type.—Even low-lying lands situated on the west coasts of continents are cool enough in winter to cause some condensation from the moist westerlies, and on the windward side of high lands in their path rain falls frequently at all seasons of the year, with a maximum in winter.

The continental type.—Having precipitated their moisture on any high lands they have encountered, the winds continue their journey to the east and north-east in a relatively dry condition, and as a consequence the central and eastern regions of the Americas and Asia within the zones show, on the whole, typical "continental" climates, with **deserts** in places. The semi-arid condition of the Great Basin of North America, between the Sierra Nevada and the Cascade Mountains to the west and the Rocky Mountains to the east, is a well-known example of such deserts; and the Shingle Desert of Patagonia (Fig. 210) furnishes another. Over the continents in general, the maximum rainfall is in summer; it is due chiefly to monsoons and cyclones.

The effect of south-westerly winds blowing from the ocean is well illustrated by the contrast between the oceanic climates of British Columbia and the British Isles, and the continental climates of Labrador and Kamchatka, all near the ocean and in the same latitudes (50°–60° N.). In these examples, however, the modifying influence of the surface currents in the Pacific and the Atlantic (Chap. XI.) must be borne in mind.

The north temperate zone.—The westerly winds, which are thus dominant over the temperate zones, are, however, much less constant in force and direction than the trades, largely because of the disturbing effects of local changes in temperature and pressure. This is especially the case in the northern hemisphere. On the large scale such changes may produce *monsoon* effects, as on the east coast of Asia, where the direction of the winds is completely reversed from summer to winter (p. 352); on a smaller scale they give rise to systems of low and high pressures—*cyclones and anti-cyclones*—which determine the weather throughout a great part of the year. The extreme changeableness of the weather of the temperate zones—which forms one of the points of contrast with the tropical zone—is to be attributed largely to cyclones and anti-cyclones. Though immensely inferior in severity to tropical storms, our cyclones succeed each other so rapidly—especially in winter—that as "climatic controls" they far outweigh tropical storms in importance.

In both the north and the south temperate zones, climate is a matter of **seasonal variations of temperature** rather than of rainfall. It is, indeed, the great difference between winter and summer temperatures found in the north "temperate" zone (most notably

in Eastern Siberia) which furnishes the chief objection to such a misnomer as the word temperate. Within the "continental" regions of this zone the summer is in places quite as hot as in the tropics, while the winter is frigid in its severity. The mean daily range of temperature is less than the mean annual range—a state of things exactly opposite to what obtains in the tropical zone. Further, in the north temperate zone there is a greater difference between the marine and continental types of climate than is found in the tropics.

The south temperate zone.—Owing largely to the great preponderance of water over land in the southern hemisphere, the south temperate zone as a whole exhibits much smaller annual variations in temperature than the northern, and may be described as truly temperate. As an examination of Figs. 174 and 175 shows, the summers are on the whole cooler in this zone than in corresponding northern latitudes, and for that reason agriculture cannot be carried on so successfully. In this zone, moreover, the westerlies are but little affected by cyclonic and anti-cyclonic whirls, and the "brave west winds" blow with great steadiness and strength.

The sub-tropical belts.—On the *western* coasts of the continents, in latitudes between about 28° and 40° in both hemispheres, the climate is controlled alternately by the trade winds (in summer) and the westerlies (in winter). They are characterised, therefore, by hot, dry summers, and by mild winters in which moderate (Fig. 209) and irregular rains alternate with the prevailing sunny weather. The mean temperature of the coldest month rarely reaches freezing point. This type of climate is often known as the **Mediterranean climate**, because it extends over a greater area in southern Europe, northern Africa, and eastward to Persia, than in any other part of the world. California, northern Chile, and the south-western coasts of Africa and Australia are favoured by similar climatic conditions.

The Mediterranean region has several minor advantages—due to local conditions—over these countries. The Mediterranean Sea causes the temperature to be more equable; the ranges of mountains to the north protect it from cold winds (the Sierra Nevada, however, has a like influence in favour of the Californian climate), and their slopes give to its northern limits the benefits of a sunny southern exposure; while the dry north-east trade winds of summer are strengthened by the position of the Desert of Sahara, which is a region of low barometric pressure. Further, the prevailing winds from the ocean in winter are warmer than those blowing over the sub-tropical western coasts in other parts of the world.

The *eastern* coasts of the continents in the same latitudes, however, have often summer rains from the monsoons, which interfere with the normal course of the sub-tropical trade winds; while in the interiors there is a tendency to spring and autumn rains.

The changes in climate from the equator polewards are shown admirably in South America (Fig. 210), where the characters of the oceanic and continental types of the various zones succeed each other with great regularity.

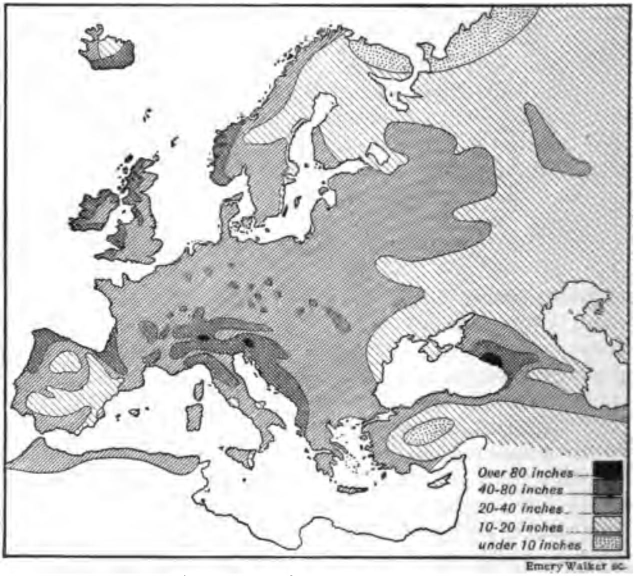


FIG. 209.—Rainfall map of Europe.

Climate of the British Isles.—The Meteorological Office has published an interesting summary of observations of barometric height, temperature, rainfall and bright sunshine, made during the past quarter of a century at a large number of stations in different parts of the British Islands. The following are a few of the facts brought out by the comparison of results:

The average readings of the **barometer** are much lower over the northern and north-western portion of the kingdom than in the south and south-east during all the winter months, and this explains the great predominance of westerly and south-westerly winds which blow over us from the Atlantic (Figs. 212 and 213). In the summer

the barometer readings are much more uniform over the whole country, and the winds are, consequently, of less strength and more variable in direction. The lowest **mean temperature** occurs nearly always in January over the whole country, and it ranges from 37° F. in Scotland and the English Midlands to 45° F. at Scilly, and 44° F. at Valentia. The highest mean temperature occurs in July and August, these two months being about equally

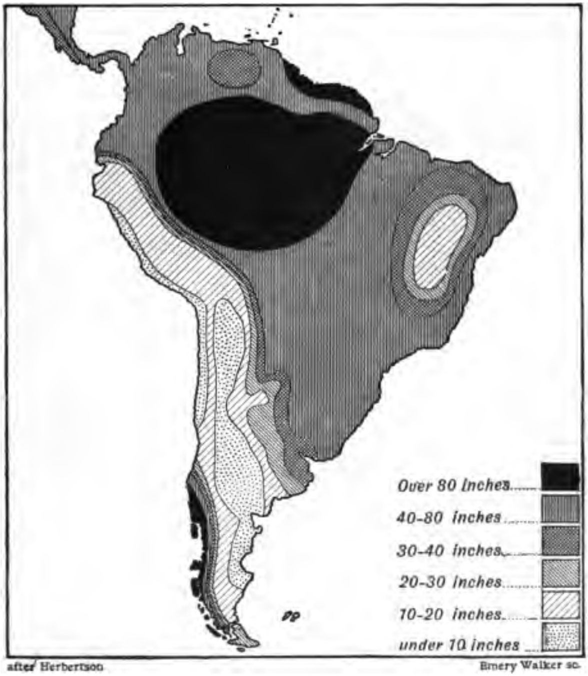


FIG. 210.—Rainfall map of South America.

warm in all parts of the country. The mean at the Scottish stations is 56° F., in Ireland 59° F., and in England 61° F. London and Jersey enjoy the highest summer mean temperature, the average being 63° F. The values of **absolute minimum temperature** show that in December, January and February, the temperature occasionally falls below 10° F. in different parts of the kingdom; but readings below 0° F. are extremely uncommon. Frost may occur in any part of the country in April, and it

sometimes occurs in May, except at the extreme western stations. Frost occurs in many parts of Great Britain in September, and is of frequent occurrence in October and November, readings falling below 20° F. in the latter month. As to **rainfall**, after Seathwaite and its neighbourhood, the heaviest rainfall occurs at Glencarron, where the total fall for the year is 86 in., and at Fort-William, where it is 77 in. One of the lowest annual rainfalls is 23·3 in. at Cambridge. In London, the total for the year is 24·8 in. The average annual rainfall for the British Isles is about 39½ in. The driest part of the year is March in the Eastern and Midland districts of England, April generally in Scotland, Ireland and the west of England; while in the south-west of England it is as late as May. The heaviest rainfall in England is mostly in October (Fig. 211); but in Scotland and Ireland it is far more irregular, occurring sometimes in winter and sometimes in summer.

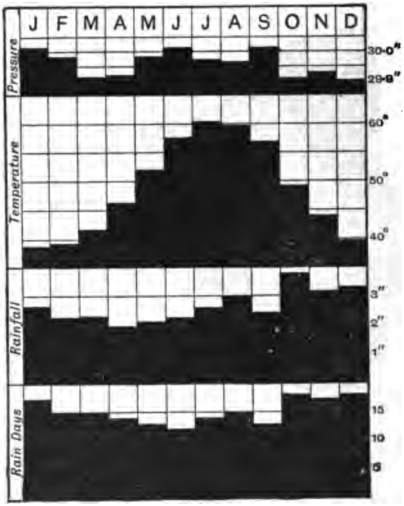


FIG. 211.—Monthly averages of climatic factors in England from 1881 to 1910. (Marriott.)

Seasonal variation in the English climate.—In an interesting paper,* Mr. W. Marriott gives the following results obtained by averaging the monthly climatic records of the past thirty years.

January is the coldest month; after which the **temperature** rises month by month until July. In August it is slightly lower, after which the temperature falls again—the fall from September to October being very abrupt.

The **rainfall** curve shows that April and May are the driest months, after which the rainfall increases to August (which is really a wet month), then falls considerably in September, but the maximum occurs in October; November and December are also wet months. The month with the least number of rain

* Marriott: "Variations in the English Climate, 1881-1910." (*Q.J. Roy. Met. Soc.*, July, 1911.)

days* is June, with 12 on the average; May and September are the next driest months. October and December are the months with the greatest number of rain days. September, in fact, comes out in all the elements as a fine month.

The **atmospheric pressure** is high in January and February, low in March and April, high from May to September, and low from October to December. The fall from September to October, and the rise from December to January, are very pronounced.

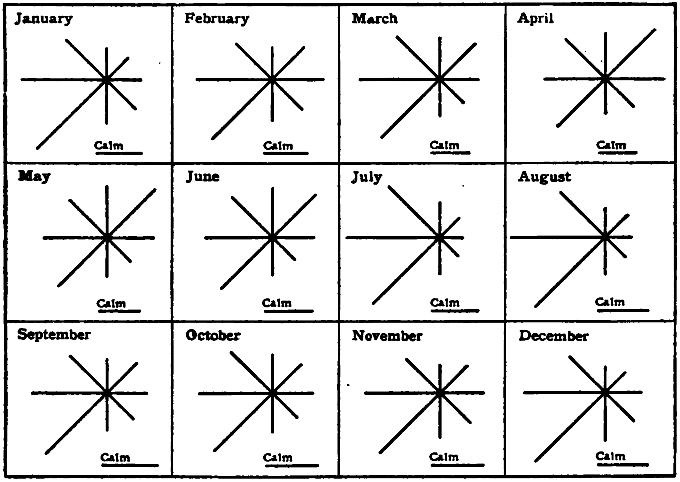


FIG. 212.—Average monthly proportions of wind-directions in England from 1881 to 1910. (Marriott.)

The prevalence of the **winds** from each point of the compass is shown in the wind-roses in Figs. 212 and 213. The winds from the south-west and west are very pronounced in most months, except in the spring, when there is a large percentage of north-easterly winds. This is brought out very clearly by combining the values for south-westerly and westerly winds as representing the "south-westerly type," and also those for north-easterly and easterly winds as representing the "north-easterly type" of winds. In July and August the winds are most distinctly of a westerly type.

The percentage of calms shows that March, April and May—especially April—are the windiest months; that is, the months

* A "rain day" is taken to be a day on which 0.01 inch has been recorded.

in which the least number of calms is reported at 9 a.m. and 9 p.m. The calmest months are September, October and November — especially September.

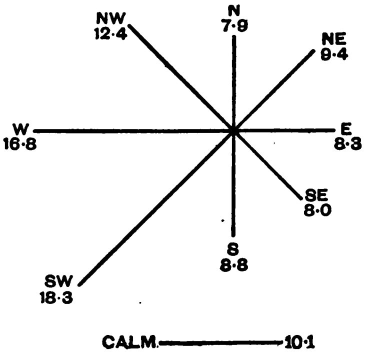


FIG. 213.—Average annual percentage of wind-directions in England from 1881 to 1910. (Marriott.)

The most **cloudy months** are November to February, and the least cloudy months May, June and September. The winter months have also the greatest **relative humidity**, while the spring and summer months, April to August, have the least relative humidity, May being the driest month of all.

Rainfall in England.—The **distribution** of the rainfall in this country (Fig. 214) is explained easily. Since the mountains near the west of England form three groups, viz. those of (1) Westmoreland and Cumberland; (2) Wales; (3) Cornwall and Devon; and since in addition to this the prevailing winds blow from the south-west, the rainfall in these districts will be much higher than elsewhere. The annual rainfall in parts of Cumberland is above 75 inches, while at Seathwaite it averages 135 inches, and at the Stye Head, a mile away, it is about 170 inches, which is the greatest recorded annual rainfall in Europe. In the second of the groups of mountains mentioned, the greatest rainfall occurs in the neighbourhood of Blaenau Festiniog, where the annual rainfall reaches upwards of 75 inches. This amount is also recorded in the third mountainous district, in the locality of Dartmoor. Throughout the Lake country the rainfall is over 50 inches in the year, and the same is true of all the mountainous parts of Wales and the higher portions of Devon and Cornwall. If we draw a line from the middle of the Cheviot Hills almost due north and south to Birmingham, and another from this place to Liverpool, we shall have included an area in the north-west where the rainfall varies between 30 and 40 inches per year. The same numbers apply to that part of the southern counties south of the Downs, and to the parts of Gloucestershire round the Cotteswold Hills. The central parts of England as far east as Oxford possess a rainfall of from 25 to 30 inches, while that of the eastern counties as far west as this university town is below 25 inches in the year.

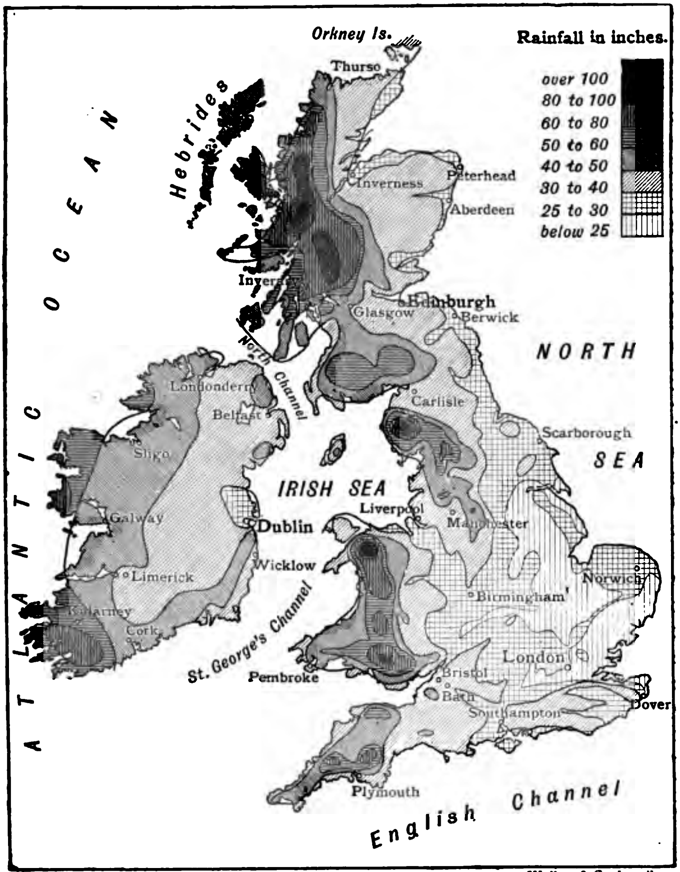


FIG. 214.—Rainfall map of the British Isles, showing mean annual precipitation.

42. THE POLAR ZONES.

The limits of the zones.—As limited by the Arctic and Antarctic circles, each polar zone has an area of about $\frac{2}{25}$th of that of the hemisphere. Defined by the isotherm of 50° F. for the warmest month—the polar limit of forest trees and cereals—the margin of the north polar zone departs considerably, in places, from parallelism

with the Arctic circle, in accordance with the influence of the great land masses upon the distribution of temperature. On the other hand, the corresponding isotherm of the southern hemisphere, freed from the disturbing effects of continents, is roughly parallel to the lines of latitude.

The temperatures of the zones.—In spite of the great amount of solar heat received by the polar zones at their respective summer solstices, their mean annual temperatures are the lowest known. This is a result, chiefly, of the large amount of heat which, without raising the temperature, is required to melt the ice and snow (p. 313); the extent of the winter—when the sun is below the horizon for periods varying, with the latitude, from 24 hours to six months at a time—further neutralises the effects of the summer. On the other hand, the lowest air temperatures yet recorded for polar zones* fail to reach the minimum (−90° F.) for eastern Siberia just outside the boundary line.

South of lat. 70° S. the Antarctic regions appear † to be colder than the Arctic, and over the south polar zone generally the summers are colder than in the north. This accounts for the extreme dearth of vegetation in the Antarctic as compared with the Arctic regions.

As in the adjoining parts of the temperate zones, it is found that the autumns are warmer than the springs. The "lagging" of spring, is, again, to be explained by the absorption of so much heat by the melting ice and snow. The process is naturally more retarded where the surface is level and the water produced by melting is unable to drain away. Such places remain deserts. Where, however, the surface slopes to allow of drainage, and the soil beneath can be warmed, the brief summer often induces the growth, in the Arctic regions, of a veritable garden of flowers. The temperature is distinctly lower in eastern than in western Greenland.

Winds and rainfall.—Owing to the absence of large irregular land masses in the Antarctic, the winds there blow with great regularity from the east and south-east—apparently from an enormous high-pressure system, or anti-cyclone, round the pole. This is surrounded by a low-pressure girdle at about the Antarctic circle. In the Arctic regions the winds are much less regular.

The polar zones are, naturally, more or less invaded at their margins by the westerly winds of lower latitudes, which are associated with cyclonic systems. At the margins, therefore, the

* The lowest reached in the *Fram* expedition was −52.5° F.

† Hann.

rainfall is under cyclonic control. Nearer the poles, however, there is a relative absence of cyclones and a scarcity of rainfall, especially in winter. The air is, indeed, so cold as to be capable of holding but little water vapour. The slightly warmer winds of summer take up the increased amount of water evaporated then, but it is soon precipitated, usually as snow.

The severity of the climate of Greenland, as well as of Victoria Land in the south zone, is somewhat mitigated by irregular winds blowing *down* the mountains and becoming warmed by the increased pressure. The "Föhn" and the "Chinook"—the warm, dry winds respectively descending the northern slopes of the Alps and the eastern slopes of the Rockies—are of similar nature.

EXERCISES ON CHAPTER XV.

1. In what parts of the world is the difference of temperature between the hottest and coldest months (*a*) greatest, and (*b*) least? How do you account for the facts? (O.J.)

2. State some of the circumstances that determine the climate of a place, giving examples. (L.C.C.)

3. What are the chief differences between the climate of a place in the tropics and that of one in the British Isles? Account as far as you can for the differences you mention. (O.P.)

4. What is meant by a "Mediterranean climate"? Where is such a climate found? Account fully for it. (L.C.C.)

5. Compare the climate of the west coast of Norway with that of the east coast of Sweden; and the climate of Simla with that of Lahore. In each case explain the difference. (C.S.)

6. Compare the winter and summer climate (*a*) of western Europe with those of the west side of North America, and (*b*) of eastern Europe with those of the east side of North America. What explanation do you give of the differences? (Prel. Cert.)

7. Robinson Crusoe classifies the climate of his island so—

Middle of February	to	middle of	April	= Rainy season;
"	April	"	" August	= Dry season;
"	August	"	" October	= Rainy season;
"	October	"	" February	= Dry season;

and adds that, for his barley and rice, he has two seedtimes and two harvests every year. From the information here given show that Crusoe is right in saying that the island cannot be a part of Europe. (Prel. Cert.)

8. In the British Isles winds from the W. and S.W., as a rule, are warm and generally rain-bearing, and winds from the E. and N.E. are cold and generally dry. Account for these differences. Compare

the characteristics of the prevailing winds of the British Isles with those of the United States of America and India. (Prel. Cert.)

9. State and account for the chief characteristics of a land climate as regards variation of temperature, amount of rainfall, and distribution of wet and dry seasons. Give examples. (O.J.)

10. Describe and account for the differences in the climate on the East and West coasts of *one* of the following regions: (*a*) Northern Scotland; (*b*) Southern India; (*c*) the southern part of South America. (C.J.)

11. Mention the climatic zones of the northern hemisphere, giving a description of their limits and characteristics. (C.J.)

12. Write an account of (*a*) the position and extent, (*b*) the climate, (*c*) the physical features of the desert region of Australia. (C.S.)

13. Describe and explain the distribution of rainfall in South America. (C.S.)

14. Describe, broadly, the relief of North America, and point out any peculiarities of the climate immediately resulting from it. (L.M.)

15. Into what climatic regions would you divide Australia? Give their characteristics. To what extent are their differences due to the relief of the continent? (J.B.M.)

16. State as precisely as possible which parts of the world have very great rainfall. Account for the facts. (J.B.M.)

17. It is found that on the whole that the greatest annual rainfall occurs near the equator, and the amount is less the higher the latitude.

How do you account for this? Mention an important region which forms an important exception to this rule, stating how and why it deviates from the rule. (O.J.)

18. Compared with central England, the climate of Cornwall is noted for (*a*) cool summers and mild winters, and (*b*) abundant rainfall. How do you account for these facts? (O.S.)

19. Compare the climates of south-east and south-west England (say of Kent and Cornwall) in summer and in winter, and give reasons for any differences. (L.J.S.)

20. Give some account of the climate of the British Isles, pointing out the effects of the physical configuration of the country, the prevailing winds, and the surrounding waters.

The mean annual rainfall at Harwich is about 23 inches and at Belmullet, on the west coast of Mayo, about 50 inches. How do you account for this difference? (O.J.)

21. Bordeaux and Vladivostock are in nearly the same latitude. Explain the great difference in the climates of these places. (C.J.)

22. Cork, London, Dresden, and Kief are nearly in the same latitude. What are the differences of climate between these places, and how do you account for these differences? (C.J.)

23. "The winter climate of the British Isles is more temperate than is justified by its latitude." Enumerate briefly the causes of this. How does this anomalous climate affect the products of these islands and the industries of the people? What other insular areas with approximately the same latitude lack this anomalous climate? (C.S.)

24. Mention some district near a large ocean where the rainfall is slight, and another far from the coast where the fall is heavy. Account, in each case, for these conditions. (C.P.)

25. What are the different factors that cause two places on the same latitude to vary in climate? Give an illustration for each different condition mentioned. (C.P.)

26. It is usual to treat the portions of Europe and Africa which border upon the Mediterranean Sea as a distinct geographical region. What characteristics justify this treatment? (Cert.)

27. State which side of Great Britain has the higher and which the lower rainfall. Explain the difference and point out any influence which it has on the agricultural or manufacturing industries of the country. (C.J.)

28. Explain exactly what is meant by the statement, "The average rainfall of the Thames basin is 26 inches." What are the chief causes that determine the distribution of rain? (C.P.)

29. Describe shortly the distribution of rainfall in Australia. What are the three main winds from which the rainfall is derived? (O.S.)

30. In what parts of the world do we find autumn and winter rains prevailing? Give what explanation you can.

31. The centre of Australia, Tibet, the Sahara, and the plateau of the Western United States have very little rainfall. Can you account for this by any general principle? (L.C.C.)

32. Give a full account of the distribution of rainfall in Africa, and show how it affects vegetation.

33. Which are the least rainy parts of the British Isles, and why? (O.H.L.)

34. What is approximately the average annual rainfall in the district in which you are examined? Explain the causes which affect the rainfall in that district. (C.S.)

35. To what extent is it true that the average amount of annual rainfall is greatest at the equator and diminishes towards the poles? Account for the facts. (O.S.)

36. State, with reasons, which of the following towns are warmest in January:—(*a*) Melbourne or Brisbane, (*b*) Lisbon or Madrid. State also, with reasons, which of the following have the greatest annual rainfall:—(*a*) Bergen or Stockholm, (*b*) Constantinople or Cairo. State, with regard to any *two* of the following districts, whether they receive the bulk of their rainfall in the cold season, or the hot season,

or pretty equally all the year round:—Italy, the Amazon basin, Ireland, the plain of the Ganges, Southern Russia. (N.F.U.)

37. Discuss briefly the causes of differences of Climate in different parts of the Earth, showing especially what conditions have produced desert areas now existing. (N.F.U.)

38. The chief characteristic of the climate of the Mediterranean region is that most of the rain falls in the winter months. Explain fully how this occurs.

39. In India persistent winds blow for six months in one direction followed by persistent winds for six months in the opposite direction. What effects have these winds upon that country? Describe the climate usually possessed by a country which is the middle of a continent and a long way from the sea. (P.T.)

40. Contrast the climate of the Scilly Isles with that of the Orkney Islands (*a*) in summer, (*b*) in winter. (J.B.M.)

41. "In the trade-wind belt dry regions are found towards the western sides of the land masses while in higher latitudes they occur towards the east." Explain the reasons for these facts, and give examples in illustration of them. (O.J.)

42. The south-west of Cape Colony is said to have a Mediterranean type of climate. Explain fully what this means and how it is brought about. (J.B.M.)

43. Mention the parts of England which have the lowest rainfall, and give the reasons for this distribution. (J.B.M.)

44. Contrast the climate of eastern Canada with that of the British Isles, and account for the differences. (J.B.M.)

45. In what season of the year does rain fall in the different parts of South America? Account as fully as you can for any facts that you mention. (L.M.)

46. Compare the climate of New Zealand with that of the British Isles, and explain the causes of such similarities as you mention. (L.M.)

CHAPTER XVI.

THE GEOGRAPHICAL DISTRIBUTION OF PLANTS.

43. CIRCUMSTANCES AFFECTING DISTRIBUTION.

1. The loss of water vapour by leaves.—(*a*) Cut off a leafy twig from a sycamore (Fig. 217), beech, oak, or other "broad leaved" tree, and leave it exposed to sunlight for an hour or two; notice the change in the appearance of the leaves. If possible, weigh the twig before and after the experiment.

(*b*) Put a similar twig in the dark for the same length of time; again notice the leaves. Is the difference in result due to lack of light or lack of heat? To test this, keep, if possible, a similar twig in the dark in a fairly warm place. Do the leaves wither as much as in (*a*)?

(*c*) Smear with vaseline the *lower* surfaces of some of the leaves of such twigs and again expose to sunlight. Do the smeared leaves remain fresh longer than the others?

(*d*) Make observations similar to the above on leaves and branches of herbaceous (soft-stemmed) plants from the garden or field.

(*e*) Arrange herbaceous plants with their roots (washed free from earth) dipping in water, and also leafy twigs of broad-leaved trees with their ends (freshly cut whilst under water) in water, and expose to sunlight. The leaves remain fresh; why? Which part of a plant usually takes up its water supply? What was the cause of the withering of the leaves in the foregoing experiments?

2. The effect of chilling the roots.—Repeat Expt. 1 (*e*) above, but put ice in the water to keep the roots very cold. Do the leaves wither although the plant is well supplied with water? What, evidently, is the effect of cold on the power of water absorption by roots? Would it be to the plant's advantage to give off water freely by the leaves when the roots were chilled? Suggest a reason why most of our forest trees shed their leaves in winter. Suggest a reason why most

of our herbaceous plants "die down" to the ground in winter, even though they may survive the winter by means of underground parts.

3. **Evergreen plants.**—What forest trees found in this country are evergreen? What other British plants, growing in the open, retain their leaves in winter? Examine and experiment with their leaves, and describe the shape, texture, surface, etc., of any leaves which you find to give off water very slowly. Classify such plants into groups according as they grow wild in very dry or very cold situations.

4. **Characteristic British vegetation** (*Outdoor work*).—Take advantage of excursions, etc., particularly in your own county, to acquire gradually a knowledge (*a*) of the extent of grassland, including cornfields; and of the areas covered by (*b*) forest trees bearing leaves which are shed in winter, (*c*) evergreen trees, (*d*) low shrubby plants (heath, etc.), mosses, etc.

Indicate each by a distinctive colour-wash on a map.

Which of these are found on high bleak land, on sheltered hillsides, in well-watered valleys, and over well-watered plains respectively?

In each group try to learn the names of the commonest plants.

5. **Influence of temperature.**—What plants, grown in hothouses, are unknown in the open in this country. Learn the usual temperature inside as many hothouses as you have access to. Examine isotherm maps of the world to find which countries have such temperatures.

The relation of plant structure to habitat.—The most casual acquaintance with plants growing under natural conditions is sufficient to convince any one that certain forms of vegetation flourish most easily in marshy ground, others in dry soils, and still others in situations which are intermediate in character. Similarly, plants at home in sheltered situations are in many cases unable to live in places exposed to strong winds; while others cannot endure the low temperatures associated with circumstances otherwise suitable. The conditions of moisture, temperature, soil, and the like under which any particular kind of plant habitually grows are said to constitute its **habitat.** Thus mountains, moorlands, and ditches form the respective habitats of the Scotch fir, heather and the common sedge in our country.

A closer knowledge of the means by which plants are adapted to their environment reveals **the paramount importance of the water-supply** as a factor of the habitat. Indeed, the danger of becoming

too dry is on the whole the greatest which plants in general have to face. Whenever green plants are exposed to light they are losing moisture in the form of water vapour, which is given off, for the most part, by the leaves in the process known as transpiration. So long as an abundance of water is forthcoming from the soil to replace this loss, free transpiration has no ill effects. It becomes highly dangerous, however, if for any reason the roots are unable to supply enough water to keep pace with it. Such a state of actual or physiological drought may arise from very varying circumstances.

Among the commonest are, first, the **lack of water in the soil.** This condition is found in deserts and in smaller local areas in all parts of the world. It naturally offers the greatest difficulties to plant life where high temperatures or dry winds join with bright sunlight in promoting transpiration.

Secondly, the fact that, when chilled, roots become, as it were, "numbed" and unable to absorb water easily, even from moist soil, must be noted. It is this difficulty, brought on by very *cold weather*, with which plants in our own and similar climates are compelled to cope in winter. Those which have no other means of limiting transpiration must resort to such extreme measures as the sacrifice of their leaves in the case of woody plants (trees and shrubs), or the death of all parts above the ground in the case of soft-stemmed (herbaceous) plants, if they are to survive the winter. Plants which shed all their leaves at definite seasons are described as *deciduous*.

A third source of difficulty is found by plants living in soils containing appreciable quantities of *salts or organic acids*, because these also interfere with the absorption of water by roots. The curious result is that plants growing in bogs containing decaying vegetation, or in salt marshes, need some means of checking transpiration, in order to escape water-starvation.

Plants which are adapted for life under such conditions of physical or physiological drought as are described above are called **xerophytes** or drought-plants. They are sometimes said to be "xerophilous" or drought-loving, though in many instances the conditions of their life are probably more to their disadvantage than their advantage. Since transpiration is essentially the work of leaves, it is by modifications of the leaves that xerophytic plants chiefly provide against drought. The leaves are succulent, fleshy, leathery, hairy, covered with wax, rolled up, needle shaped (Fig. 219), very small, or even absent altogether, in different

xerophytes, since each, or a combination, of these characters reduces the extent of transpiration.

At the other extreme is the condition of having **an abundance of moisture at all times**, under which plants live in soil of moderate temperature which is always able to afford a regular and adequate supply of water to the roots. In these circumstances, all serious interruptions of growth are avoided, and the plants are mainly *perennials*, that is, they live on from year to year. Among perennial plants, **trees** are the dominant type, so that well-watered countries in the tropical and temperate zones are naturally forested.

In countries having a regularly **recurring dry season**, trees and other perennials are scarcer, and their place is taken by *annuals*. These are plants which live only during the moist season, towards the end of which they produce seeds capable of withstanding the coming drought. The plants then die, but their seeds survive, to germinate and pass in their turn through the same life-history when the necessary moisture is available. **Grasses** are, on the whole, the most successful of annuals, and they form the greater part of the vegetation of countries having this type of climate.

Plants characteristic of climates which show no extremes of wet and dry, or of hot and cold seasons are called **mesophytes**. In a general sense **British plants** fall in this group, although most of them need to adopt certain precautions against the cold—and consequent difficulty of absorbing water—in winter. The "broad-leaved" deciduous trees mostly belong to this group.

In general, the main groups of "plant communities" outlined above merge gradually into each other, as climates themselves merge gradually into each other.

Temperature and soil as factors in habitat.—It is well known that many plants which are abundant in the tropics cannot grow—except when provided with artificial heat—in temperate countries. Although the temperature of soil and air does operate directly to some extent in limiting the distribution of plants, its effect is chiefly indirect, and a result of the influence which temperature has upon the ease or otherwise with which the plants absorb or retain water. Similarly, certain plants grow far more abundantly in chalky soil than in clay, and *vice versa*, and there is a natural tendency to suppose that the *chemical* composition of the soil accounts for the difference between the characteristic plants. It is, however, the *physical* condition of the soil—dry, easily warmed and porous in the case of chalk, "heavy" and largely impervious to both air and water in the case of clay—which is chiefly responsible, by placing a smaller or greater amount of heat, water and air at the disposal of the roots.

Methods of dispersion.—For a description of the various means which plants adopt to scatter their seeds or get them scattered by the wind, by water, or by animals, a text book of botany should be consulted. We are concerned here chiefly with the dispersion of plants, by seeds or otherwise, from country to country. Besides the intentional introduction by mankind of useful plants, and accidentally of those undesirable plants called weeds, account must be taken of the action of winds in the gradual dispersion over continents, and from time to time across narrow seas, of plants producing light seeds; of the agency of birds in carrying seeds uninjured either in their digestive organs or attached by mud to their feet; of transportation by oceanic currents, icebergs, floating tree trunks, and other means.*

Obstacles to dispersion.—In spite of these and other methods by which plants may "spread" from country to country, it is common knowledge that plants do not by any means occur invariably in all habitats which are suitable for them. Similar conditions of climate and soil in different parts of the world often support a markedly different flora. The fact may be attributed to one of two causes: migration may have been prevented by barriers, or the plants may have reached a suitable habitat only to find it occupied already by species which they were unable to oust.

The principal **barriers** preventing unlimited colonisation are deserts, wide oceans and high mountain ranges. It is difficult to believe that seeds of flowering plants could be carried, except in the most improbable circumstances, across such barriers, by any means other than human agency; and none but comparatively recent migrations can be attributed to mankind. On the other hand the minute dust-like spores of many very simple plants may conceivably have attained a world-wide distribution by means of the wind alone.

Again, the intensity of **competition** may easily explain why a newcomer may fail to obtain a footing in a habitat quite suitable to its needs. Only if it possessed some advantage over those already settled in the station, would it have any chance of beating

* See Darwin's *Origin of Species*, chap. xii.

In 1883 all plant-life on the island of Krakatoa was destroyed by a volcanic eruption (p. 173). In 1906, 137 species of plants were collected in a few hours by a party of botanists on the island, who found trees 50 feet high as well as thick jungle. (*v.* Seward's *Links with the Past in the Plant World*: Camb. Univ. Press.)

them in the struggle for existence, since only the "fittest"—that is, those best able to take advantage of the favourable circumstances and to overcome the difficulties of the situation—can survive where every inch of room is keenly contested.

Discontinuous distribution.—On the assumption—which modern biologists feel quite justified in making—that the same species of plant or animal has not originated more than once in the history of the earth, it is clear that if the same species occurs on both sides of an impassable barrier, the species is of greater age than the barrier. Though now discontinuously, it must once have been continuously distributed.

Further, if any particular species occurs only at widely separated stations, although suitable habitats exist between these stations, it is highly probable that the species is an ancient one—formerly distributed continuously—which for some reason has become extinct over the greater part of its range, surviving here and there in isolated areas owing to freedom from competition or other favouring circumstances. Some of the results obtained by applying these principles are highly interesting.

The presence of Arctic species of saxifrage, etc., on the nigher slopes or summits of mountains of the Swiss Alps and even of some of our own mountains, while they are absent over all the intervening low-lying land, is usually explained by the fact that in the great Ice Age already referred to (p. 165), the climatic conditions now found in the Arctic regions extended as far south as central Europe. At this time, only plants able to withstand great cold could survive; the former flora of central Europe retreated to the south, and its place was taken by Arctic plants. When at length milder conditions supervened, the plants of the south gradually regained the supremacy, and the Arctic forms of central Europe were restricted to the bleak mountain heights, becoming extinct in the lowlands.

An example of a different kind is found in the curiously scattered distribution of the monkey-puzzle trees, or Araucarias. They are found native on the slopes of the Andes of Chile, in Brazil, in Norfolk Island, in New Zealand and New Caledonia, and scarcely anywhere else. This suggests that Araucarias are extremely ancient types of trees; and the surmise is borne out by geological evidence, which shows that in the Jurassic period

(p. 195) they had practically a world-wide distribution.* Since that time they have been gradually crowded out of existence by more modern and better-equipped trees in nearly all parts of the world.

44. THE CHIEF ZONES OF VEGETATION.

Plant distribution dependent upon climate.—After what has been said in the foregoing section as to the importance of moisture and temperature as factors in plant habitats, it will be expected that the general distribution of plant associations will have a direct relation to the great climatic zones. The subject must now be considered from this point of view.

Vertical and horizontal distribution.—The influence of elevation in controlling temperature and general climate has been considered on pp. 287 and 373. The changes in climate to be found between the base and the summit of a mountain are naturally reflected in the plant life, so that on ascending a high mountain in the tropics, a traveller encounters a succession of plant types broadly similar to the order in which they would be met with on a journey polewards, and may pass in a few hours through vegetation characteristic of countries thousands of miles apart.

Tropical forests.—In the equatorial belt of climate there are very frequent—often daily—**heavy rains,** amounting to at least 70 inches annually, **with a continuously high temperature**; and on the lowlands and in the valleys the exuberant vegetation grows without hindrance. It forms dense forests, which stretch across Africa, in a band from 100 to 200 miles wide on the north of the Gulf of Guinea and then broadening to cover most of French Congo and the Congo Free State to the great Lakes; and in South America extend over the basin of the Amazon and fill the valleys of other rivers of Brazil. Similar conditions are found skirting the coast lines of the Malay Peninsula and Archipelago. Among the most important, economically, of the plants found in these forests are the various rubber and guttapercha vines and trees of the Congo, Brazil and East Indies; and trees

* "In the Carboniferous, Permian, and some later periods a vast continent extended from Eastern Brazil to Australia, including Southern Africa, the Indian Ocean, and Southern India." (J. W. Gregory's *Geology*: Dent.)

yielding valuable timber—such as ebony, mahogany and rosewood —or drugs (*e.g.* quinine).

The winding and coiling creepers and climbers (lianas), the gorgeous orchids and other flowers, are of little commercial

FIG. 215.—Scene in a tropical forest.

importance, but none the less remarkable. In the **secondary forest**, which springs up where the virgin forest has been cleared, are oil palms and sago palms and plantations of rice, manioc, arrowroot, sugar (except in the Congo and Amazon basins), coffee, cacao (cocoa) and tobacco.* Along the sea shore and bordering the

* *Rice* is also cultivated in parts of the "temperate" zone where the necessary warmth (70° F. for six months) and moisture are available, but is most successfully grown in the monsoon regions of the tropics. *Coffee* (chiefly in Pernambuco) requires a moist climate and a temperature between 55° F. and 80° F. *Tea* (India, Ceylon, China, Japan and Java) is more hardy, being able to survive occasional cold weather.

estuaries in this belt are found swamps covered with mangrove forests.

Savannahs.—Intervening between the tropical forests and the dry deserts of the trade-wind belts, occur stretches of warm country with a **moderate rainfall** only. Here there are very few trees, but **grasses** of various kinds which afford abundant food to herds of grazing animals. In the better watered portions some amount of agriculture is possible. Such savannahs include the African Sudan, the Venezuelan "llanos," the Brazilian "campos" and the Australian "downs."

FIG. 216.—An Egyptian oasis.

The trade-wind deserts.—More than half of the land lying in the trade-wind belts consists of desert. It is in such situations, naturally, that the scanty vegetation which can exist at all will show most markedly xerophytic characters (p. 395). Along the **margins** of the deserts, where the rainfall is slightly more abundant, thorny plants—principally *acacias*—are common. This group has been said to constitute an "acacia-fringe" round all the great trade-wind deserts of the world. Gum arabic, senegal and other gums are obtained from certain species of acacia. In the **oases** (Fig. 216) and on the margins of rivers flourishes the invaluable date-pine. More typical of the **inner desert** are cacti, various very fleshy species of *Euphorbia* (allied to our spurges) which assume the most weird shapes, the "ice-plant," and the grasses called esparto or halfa. Many of the

desert plants are covered with thick flannel-like coats of hair to prevent loss of moisture. Perhaps the quaintest of all desert plants is the ancient *Welwitschia*, now limited to south-west Africa.

When the rare showers of rain fall in these deserts a host of small herbaceous plants, bearing brilliant flowers, springs up. A few days suffice for germination, flowering and the production of the seeds, bulbs, or tubers, necessary to complete the cycle at the next opportunity.

Sub-tropical scrub.—Scrub is the name given chiefly to the vegetation which occurs on the desert-fringe of countries having the **Mediterranean type of climate** (p. 381). Lacking the plentiful rainfall necessary for abundant tree growth, it forms a transition between the tropical desert-flora and the forests of the warm temperate regions. On the desert border is found the acacia type of vegetation, and it is this half desert which yields the most valuable gums and resins used in perfumery. The Mallee scrub of Australia consists of eucalyptus bushes. Grapes, oranges, figs and olives are typical products of the Mediterranean climate, and similar conditions in California, Southern Australia and Cape Colony make these countries also important centres of the wine industry.

FIG. 217.—Leaves of sycamore.

Cotton is an important crop of the sub-tropical zone. It thrives best in a deep, rich soil with a long, hot season, the atmosphere being damp during the period of greatest growth (about 2 months), but becoming drier during the ripening of the crop. (*Maize* (p. 406) also grows most successfully in a climate of this type.) These conditions are found in the Southern United States of America, which furnish four-fifths of the world's supply of cotton. India, China and Egypt come next in order in extent of cotton production.

The temperate forests.—Reaching northward and southward from the sub-tropical belts to a line which corresponds roughly with the isotherm of 50° F. for the warmest month, those lands which possess a reasonably abundant and regular rainfall are for the most part covered by forests.

Photo. W. B. Crump.

FIG. 218.—Typical English woodland scene (deciduous trees, with bracken, etc.).

In the **warmer temperate regions** and on lowlands, most of the trees are of the mesophytic type, having broad leaves, which give off water vapour freely whenever they are exposed to light. The risk to the tree—entailed by retaining such leaves through a winter considerably colder than the summer—is great, as has been explained on p. 395. The trees of these regions are therefore **deciduous**, shedding their leaves annually before winter. Typical examples are oak, beech, elm, sycamore, ash, etc.

Trees the leaves of which are specially adapted to restrict transpiration (p. 395), however, can retain their foliage safely through the winter of the cooler temperate regions and at elevations where

most of the broad-leaved trees have failed to obtain a footing. Xerophytic trees of this kind belong largely to the group of **Conifers** (cone-bearers), which includes the pines, firs, spruces, larches, cedars, cypresses, junipers, etc. Their leaves are more or less needle-shaped and leathery, with breathing-pores sunk below the surface. Larches, however, are deciduous.

FIG. 219.—Branch of Scotch pine, showing needle-shaped leaves.

Such **coniferous forests** form a belt distantly encircling the North Pole. They are the chief source of useful timber. In Scandinavia they consist chiefly of the Scotch pine, in Russia of a fir, in Asia of the Siberian larch and—further east—a species of pine. In America, spruce and pine to the west (Fig. 220), and the American larch to the east, of the Rocky Mountains, are the commonest representatives of this hardy family. It is significant that in both old and new world the larch thus replaces the pines and firs in the more "continental" climates. There are now no trees in Greenland. The conifers on the western slopes of the Sierra Nevada in California are—after certain eucalyptus trees in Australia—the largest trees in the world; * next in order of size come the conifers of British Columbia. In the southern hemisphere the coniferous forests are less continuous and more archaic in character. The Araucarias of Southern Chile, Southern Brazil, New Caledonia and New Hebrides have already (p. 398) been mentioned. Other ancient types of conifer occur in the southern forests of the Andes, in Australia, New Zealand and the Fiji Islands.

It is a curious fact that certain hardy and dwarfed broad-leaved deciduous trees—birch in the northern, beech in the

* A section of one of these trees, exhibited in the Natural History Department of the British Museum, shows 1335 rings of wood, each of which is believed to represent one year's growth.

southern, hemisphere—are able to grow even nearer the pole than the conifers.

Steppe lands and prairies.—In the temperate zones—usually *to the leeward of the forested regions,* so that they receive a smaller rainfall and experience more continental conditions generally—occur extensive tracts of unwooded land covered chiefly by **grasses** and in the warmer months bright with flowers. These constitute the steppe lands of the old world and the prairies of America. Directly

FIG. 220.—Pine forest in the Selkirks (British Columbia).

(as cereals) or indirectly (as the food of animals whose flesh is used as meat), the grasses form the chief food supply of the human race.

From southern Russia, the steppe lands stretch eastward through southern Siberia to China; in South Africa they form enormous plains (veldt); in North America they include the great prairies to the east of the Rockies, and in South America the pampas of Argentina; and in Australia the grassy plains of western Queensland and New South Wales.

The plants known as **cereals** are grasses with edible seeds, and it is, naturally, to the steppe regions that we must look for the principal sources of this all-important food-supply. Rice (p. 400), a cereal, however, requires a higher temperature and a moister

climate. "The great cereal lands of the world are found **in the continental interiors, in the regions of summer rains,** where the precipitation is sufficient. Roughly, between latitudes 40° and 52°, other conditions being favourable, we find the principal **wheat** belt; but wheat is cultivated much farther north, for example in Asia, and also farther south than the above limits. **Barley** grows over a much wider belt, both poleward and equator-ward; **oats** grow north of wheat, and corn (*i.e.* **maize**) grows south of it (p. 402). In the higher latitudes, with shorter summers, it is more and more difficult for cereals to ripen.... It is worth noting, that the wheat harvest in Argentina usually begins late in November in the north, and progresses southward until February; in India the harvest begins late in February in the south, and progresses northward until early in May. The Indian and Argentine wheat thus come to market in what is known as the 'dead season' in the other wheat countries, and therefore have an important effect on prices." *

Already more than one-third of the population of the world are regular consumers of wheat bread. About 55 per cent. of the wheat is grown in Europe, and about 20 per cent. in the United States.

The climate of the **British Isles** is very favourable to the growth of grasses. In the western counties, where the rainfall is most abundant and the winters are mildest, and also in the western midlands, the rich *pasture grasses* allow of successful cattle raising and dairy farming, with sheep-grazing on the hillsides. In the drier and warmer eastern counties, arable (*i.e.* ploughed) land exceeds permanent pasture considerably, and forms the principal *wheat* area. In the British Isles, wheat requires a mean July temperature of at least 56° F., and an annual rainfall of less than 30 inches. *Barley* has a wider range, while *oats* are so hardy that they gradually replace all other cereals to the west and north of our country.

As the forested regions of the temperate zones are succeeded to the leeward by the steppe lands, so these in their turn give place on their "continental" side to **deserts**, especially where surrounding high land has co-operated with distance from the sea in drying the prevailing winds. The "temperate" deserts reach their greatest development in the interior of Asia (*e.g.* Gobi), but are found also in Australia, North America (in south-eastern California and in Arizona) and Patagonia. The scanty plants show xerophytic characters (p. 395).

* Ward's *Climate* (Murray).

The tundra.—Polewards, the northern forests of coniferous trees and stunted birch are succeeded by a frozen treeless desert called the tundra (Fig. 221), or, in Canada, the "barren lands," which reaches to the shores of the Arctic Ocean. In summer the surface thaws sufficiently to produce a more or less swampy plain on which grow ferns, mosses and lichens, tiny willows and junipers, and also a number of Arctic herbaceous flowering plants which mature quickly and deck the ground with blossoms of astonishingly brilliant

FIG. 221.—The limit of trees in Siberia.

colours. The extremely small size of Arctic plants is explained partly by the shortness of the growing season and the general severity of the climate, and partly by the intensity of the summer sunlight, which retards growth. In winter the tundra is frozen hard and covered with snow.

North of the tundra is the perennial ice-cap on which plants are unable to exist.

The distribution of the vegetation belts, with the representative plants of each, is exhibited graphically in the following table, intended for reference only:

Climatic Zones.	Water Supply.	Average Mean Temperature.	Countries.	Type of Vegetation.	Trees and Shrubs.	Cereals.	Other Typical Plants.
TROPICAL. Doldrums.	Daily or frequent rains.	Over 80° F.	Peru, Brazil, Upper Guinea, Congo, East Indies.	Tropical Forest.	Rubber and gutta percha vines and trees, ebony, mahogany, rosewood, teak, sandalwood, baobab, sago palm, cinchona.	Rice, Millet.	Banana, manioc (tapioca), arrowroot, some cotton (Peru), coffee, sugar cane (except in Congo and Amazon basins), cacao, tobacco, sweet "potato," etc.
TROPICAL. Equatorial (general).	Summer rains.	Over 80°.	Sudan, Venezuela, Brazil.	Savannah.	As above. Scanty.	Rice, Millet, Maize.	Forage grasses.
TROPICAL. Trade-Wind Belts.	Abundant rainfall on eastern slopes.	Over 70°.	Central America, W. Indies, Guiana, Brazil, S.E. Africa, E. Australia.	Tropical Forest.	As in doldrum zone. Jarrah (Australia).	Maize, Rice.	As in doldrum zone.
TROPICAL. Trade-Wind Belts.	Lowlands and interiors dry.	Over 70°.	Sahara, Chile, Peru, Central Australia.	Desert.	Date palms near water. Acacia.		Alfalfa (for forage), cactus, agave, esparto.
TROPICAL. Monsoon Belts.	Summer rains.	Over 70°.	India, S.E. Asia, N. Australia.	Various.	As in Equatorial. Jarrah (Australia.)	Rice, Wheat, Millet.	Sugar cane, cotton, tea, jute, flax, beans, etc.
SUBTROPICAL BELT.	Winter rains.	60°—70°.	Mediterranean, Cape Colony, Southern U.S.A., S. Australia.	Scrub.	Acacia, olive, grape vine, fig, orange, lemon and other fruit trees, cistus, oleander, laurel, etc. Eucalyptus (Australia). Trees in clumps	Barley, Wheat, Maize, Sesame, Millet.	Bulbous and tuberous plants, aromatic herbs, tobacco, flax, prickly pear (a cactus), cotton.

TEMPERATE.	Warm Temperate (Marine Type).	Abundant and equable rainfall on western shores and slopes.	Warmest month over 50°. 40°—60°.	Central Europe.	Broad-leaved deciduous forests.	Oak, maples, beech, elm, ash, etc., as in England.	Rice (Lombardy), Maize, Wheat, Barley. Oats.	As in England; flax, beet, buckwheat, potato, peas, beans, etc.
				Atlantic and Gulf Plains of U.S.A.	Do.	Do., with magnolia and liquidambar.		
				Western U.S.A.	Coniferous forests.	Sequoia, redwood, etc.		
	Cool Temperate (Marine Type).	Do.		N. Europe, Siberia, Canada, S. Chile, S. Brazil.	Coniferous forests.	Pines, firs, larches; araucaria.		
	Continental Temperate.	Moderate Rainfall.		S. Russia, Hungary, Central Asiatic Plateau, "Great Plains" of U.S.A., S. Africa, Argentina, N. S. Wales, W. Queensland.	Grass land.		Maize, Wheat, Barley, Oats, Rye.	Forage grasses.
	Extreme Continental.	Rainfall scanty or absent.		Arizona, S.E. California, Atacama, Patagonia, Kalahari, Turkestan, Gobi, Central Australia.	Desert			Alfalfa (for forage), sage brush, mesquite, cactus, etc.
POLAR, - -		Low temperature causes physiological drought.	Below 32°. Warmest month below 50°	Circumpolar Europe, Asia and Canada; Alaska.	Tundra.	Dwarf willow and juniper.		Mosses, lichens; Arctic herbaceous flowering plants.

EXERCISES ON CHAPTER XVI.

1. State what areas in any *one* of the continents are densely forested. In which of these areas is the lumber industry most important, and why? Name other products of economic value besides timber which we procure from forests, and state where they are chiefly obtained. (N.F.U.)

2. Explain (*a*) why the range of temperature at Colombo in Ceylon is very slight; (*b*) why the annual rainfall at Bombay is heavy and falls mainly in summer; (*c*) why wheat flourishes in the Punjab, rice in the lower Ganges basin, and tea on the lower slopes of the Himalayas. (N.F.U.)

3. What connexion can you trace between vegetation zones and climate zones? Give examples. (L.J.S. slightly altered)

4. What climatic conditions are necessary for the existence of (*a*) deserts, (*b*) dense tropical forests? Give two examples of each. (L.C.C.)

5. There are two main types of forest: where are they found? Contrast them with reference to position, climate, and products. (C.S.C.)

6. Why does snow stay all the year round in parts of India, China and South Europe and not in any part of the British Isles? How do permanent snowfields affect rivers? What kind of trees grow near the snow-line? (P.T.)

7. Where are forests found in Australia? Give reasons for this distribution. (L.J.S.)

8. What are the reasons for the following phenomena?—

(*a*) the temperature of Iceland is sometimes higher than that of England, France and Spain;

(*b*) the July temperature of Toronto is often the same as the January temperature of Florida;

(*c*) North Alaska and the region between the Black and the Caspian Seas are both treeless. (Cert.)

9. Show that the existence of large areas of steppe and of desert is mainly determined by the amount and the period of rainfall. (Prel. Cert.)

10. Owing to peculiarities of climate, the vegetation of the peninsulas of south-east Europe exhibits marked characteristics.

What peculiarities of climate are referred to, and how is the vegetation affected thereby? (Prel. Cert.)

11. By reference to *climate*, how would you explain:

(*a*) Why *corn* is grown in Canada and not *rice*?

(*b*) Why certain regions only in the world are suitable for growing cotton?

(*c*) Why Arctic plants are found in certain areas within the tropical and sub-tropical zones? (P.T.)

12. What are the geographical conditions necessary for the production of wheat, rice, and cotton? In what parts of the world are they principally grown? (Prel. Cert.)

13. How are the successive belts of vegetation arranged on the west coast of Africa? Account for their character and distribution. (L.M.)

14. Specify, as exactly as possible, the cotton-producing regions of the world, mentioning the chief ports of export. What physical conditions favour the growth of cotton? (J.B.M.)

15. Explain why we have such deserts as the Sahara and the Gobi. How does it happen that there are oases in these deserts? (C.P.)

16. Describe and account for the positions of the chief desert regions in the world, and mention any articles of commerce that have been obtained from them. (L.C.C.)

17. In what parts of the world are deserts found? Classify the different causes which produce deserts, and explain with regard to some one desert the reasons for its sterility. (L.C.C.)

18. State the chief agricultural products of the Mediterranean region. Specify carefully any other parts of the world which have a similar group of products, and suggest reasons for the similarity. (J.B.M.)

19. State as precisely as possible the chief rice-producing regions of the world, and describe the conditions most favourable to the cultivation of rice. (J.B.M.)

20. Describe the distribution and characteristics of the chief natural vegetation regions of North America. (J.B.M.)

21. State precisely the regions of the world where tea is produced. What are the special conditions required for tea production? (J.B.M.)

22. What are the chief vegetation regions of Africa south of the Sahara? Indicate briefly the climatic factors which determine them. (J.B.M.)

23. Contrast Hindustan and Siberia with respect to climate and vegetable productions. (C.P.)

24. Where are the wheat lands in Europe? Account for their position, and compare them with any other wheat-growing areas in the rest of the world. (N.F.U.)

CHAPTER XVII.

THE GEOGRAPHICAL DISTRIBUTION OF LAND ANIMALS AND MAN.

45. THE DISTRIBUTION OF LAND ANIMALS.

The dependence of animals upon plants.—All animals obtain their food from plants, either directly or indirectly. Many animals are, of course, flesh eaters, living upon other animals; but in such cases the prey itself is usually vegetarian. To the wolf and the lamb alike, life would be impossible in a world without plants. It follows from this that the distribution of animal life on the earth must exhibit a general correspondence with that of plants. In deserts, whether of sand or of snow and ice, the dearth of plants must be accompanied by a scarcity of animals. Where, on the other hand, exuberant plant life provides an abundance of food, animals will usually occur in large numbers.

Differences of environment.—Animals, like plants, occur in certain restricted habitats, for which they are fitted by their nature. The idea of beavers in the Sahara, or of sloths in a Siberian steppe, is absurd to one knowing anything of the habits of these animals, because the conditions of their actual lives are the precise opposites of those suggested. We might expect to find an animal living where the conditions were suitable for its maintenance, but nowhere else. There is nothing intrinsically absurd, for example, in the thought of sheep in New Zealand, of tigers in South America, or of bears in South Africa. We know that sheep farming is highly successful in New Zealand; it seems likely that for tigers tropical South America, and for bears many parts of South Africa would be among the happiest of hunting grounds.

It is nevertheless a fact that there were no sheep in New Zealand until they were taken thither by man, and it is safe to assert that only in menageries are tigers to be found in South America, or bears in South Africa. Evidently it is necessary to distinguish between the animals which are native or **indigenous** in a region, and those which have been **introduced** by human agency.

Barriers.—The facts just mentioned, and others of a similar nature, show that many species of animals have been unable by their own efforts alone to reach all the regions suitable for their maintenance. Animals are prevented, in fact, by **barriers** from dispersing to an unlimited extent. For creatures which, like monkeys, cannot swim or fly, even a river or a small arm of the sea may be impassable. A stretch of desert to many animals, a snow-clad mountain range to others, may similarly prove permanent obstacles to migration.

The significance of discontinuous distribution in the case of animals is precisely the same as in that of plants (p. 398). "The greater the facilities for the transport of any species across a given barrier, the less significance will attach to its occurrence on both sides of the barrier. Conversely, when a species having few or no facilities for dispersal is found on opposite sides of an important barrier, the natural conclusion is either that the barrier is of comparatively recent formation, and that the two areas separated by it were once, so to speak, in zoological continuity, or that the species in question is a very ancient one, and was widely dispersed at a time when the arrangement of the land surface was very different from what it is at the present day. For instance, the occurrence of strong-flying birds, such as gulls and cormorants, in widely separated countries, is a fact of no significance in determining the mutual relationships of the faunæ of those countries. But the occurrence of the same species of fresh water crayfish—to which the narrowest arm of the sea is an insuperable barrier—in Great Britain and the European continent, is explained only by the fact—of which there is independent evidence—that the English Channel is of recent formation." *

The occurrence of tapirs in Further India and Brazil, and nowhere between, is, similarly, evidence of the antiquity and former wide distribution of these animals.

* Parker & Haswell's *Text Book of Zoology*, Vol. II., p. 591 (Macmillan).

From such considerations it becomes possible to understand why, between the animals native to England and those indigenous to Japan there is less difference than exists between those of northern and central Africa (separated by the barrier of the Sahara), or between those of Australia and New Zealand (separated by the barrier of the Tasman Sea). The native fauna (animal population) of England is so like that of Europe that it is said to be **continental** in character; that of New Zealand is peculiar to itself and therefore is described as **insular**.

The zoo-geographical regions.—Zoologists have mapped the surface of the earth into regions in order to group together countries the native faunas of which have most in common, and to distinguish between countries which have widely different indigenous animals. Fig. 222 shows such a division into regions based chiefly on the distribution of the hairy quadrupeds (mammals).

Animal life in the tropics.—In the tropics, conditions are specially favourable for animal life, since abundance of food is provided by the luxuriant plant growth. The large animals occur in the savannahs, however, rather than in the dense forests. Interesting differences are to be found in the animals characteristic of tropical South America, tropical Africa and the Oriental region, although the conditions of life are in so many respects similar.

In **tropical South America** are found broad-nosed monkeys, opossums, sloths, armadillos, ant-eaters, the jaguar, lama (related to the camel), peccary and a species of tapir; besides humming-birds, the condor of the Andes, the large-billed toucans and other strange birds—all unknown in tropical Africa or Asia.

Tropical Africa is the home of such "narrow-nosed" monkeys and apes as the gorilla, the chimpanzee and several baboons, as well as of the lemurs, of the giraffe, zebra and hippopotamus, the African elephant, rhinoceroses, the camel, lion and leopard. Besides these mammals there are—among birds—the ostrich, the hornbills (which much resemble the toucans of tropical America), and the sun-birds (which resemble the humming-birds). The secretary-bird is purely African in range. Tropical Africa is remarkable for the great abundance of hoofed animals (ungulates).

The **Oriental region** possesses many groups of animals (*e.g.* elephants and rhinoceroses, higher apes and lemurs) in common with tropical Africa. On the other hand, the tiger, and several species of bear and deer, which are here abundant, are not found

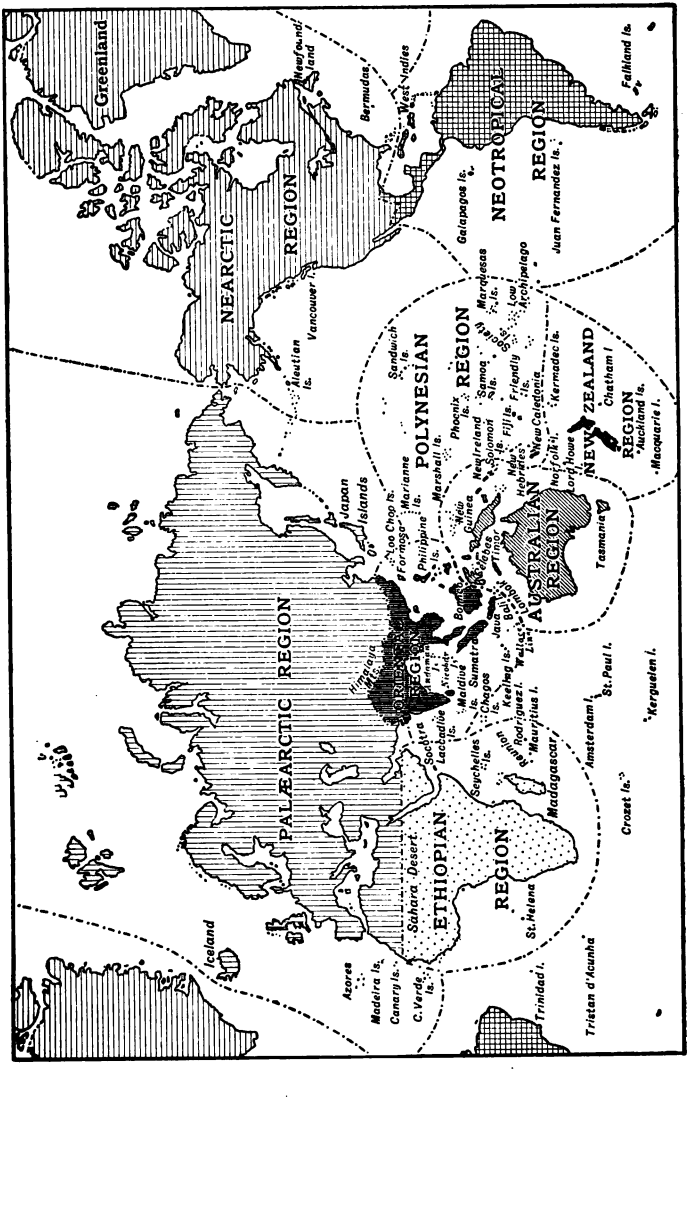


FIG. 222.—Zoo-geographical regions of the world.

at all in the Ethiopian region. Tapirs occur here, as well as in tropical South America, but nowhere else.

Animals of the temperate zones.—The **north temperate zone** includes most of Europe, of Asia and of North America. In the "old world" it is separated, zoologically, from the tropics by the desert of Sahara and by the Himalayas; while in the new world North and South America were separated by the sea within recent geological times. Throughout this zone there is a marked similarity in animal life; although certain mammals (*e.g.* opossums), birds (*e.g.* humming-birds), reptiles (*e.g.* rattlesnakes and iguanas) and members of other groups occur in North America but not in Europe or Asia; and the Palæarctic region, on the other hand, has a number of forms (*e.g.* wild horse and ass) which are absent from North America.

Within the north temperate zone exist, as has been seen, marked climatic differences and correspondingly distinct belts of vegetation; and it is natural that in each belt the conditions of life are reflected in its animal population. The opossums of North America, the squirrels of both continents, with other tree-dwelling mammals as well as birds, haunt the forests. The grazing, hoofed mammals are found chiefly on the steppes and prairies, where the grass and other herbage affords a supply of food to herds of bison, antelopes and (in the old world) buffaloes; and the gregarious burrowing marmot (commonly called the prairie-dog) of North America shows another adaptation to the same environment. The irregularity of the rainfall, and consequently of the food supply, of certain steppe lands tends locally to keep down the numbers of animals which multiply slowly, and gives a relative advantage to such prolific creatures as rodents—rats, mice, rabbits, lemmings, hamsters, marmots, etc. Peculiarly at home in the lands transitional between the steppes and the deserts of Africa and Asia, are the camel, the horse, the wild asses, and sheep and goats.

In **South America and South Africa** no general barrier exists between the tropical and temperate zones. In each continent suitability of habitat is the only factor of great importance which distinguishes the tropical from the temperate faunas, so that no hard and fast line can be drawn between them. In temperate South America, the lama, which roams over the pampas, and the vizcacha (a rodent, which, like the prairie-"dog" of North America, constructs underground cities) are characteristic. The South American "ostriches" —more correctly called "rheas"—are different in many respects from the true ostriches of Africa, but of very similar habits. The American humming-birds reach southward to Tierra del Fuego;

in South Africa—as elsewhere in the old world—humming-birds are absent, but are replaced by the sun-birds. The Cape "ant-eater" has but a distant relationship with the true ant-eater of South America.

The Australian region.—While geological evidence points to a relatively recent land connection between Asia and North America, and between the British Isles and Europe, there is reason to believe that Australia and the neighbouring islands have been separated from Asia for a very much longer interval of time. Apparently the isolation of the islands to the south-east of Wallace's line (Fig. 222) took place before the mammals common in other parts of the world had had time to migrate thither: if indeed they had come into existence at all by that period. This view explains why, at the present day, all the **marsupials** or pouched animals (including kangaroos, wombats, bandicoots, Tasmanian devil, etc.)—with the practically single exception of the opossums in America—besides all those simplest of mammals the **monotremes**, which lay eggs, are confined to this region. Animals closely related to the marsupials and monotremes of to-day once existed in other parts of the earth, as their fossil remains testify; but they were unable to withstand the competition of the better-equipped mammals which presently appeared, and they therefore became extinct. That fortunate section which had been marooned in the Australian region, however, being free from such interference, flourished, and in due course gave rise to extremely diverse types: carnivorous, herbivorous, burrowing and tree-haunting habits all being found among various marsupials. The only mammals of the higher orders which reached the region before civilised man were the dingo or Australian wild dog, and a few rats, mice and bats. The indigenous birds of the Australian region are in many respects equally peculiar, for they include the emus, cassowaries, birds of paradise, cockatoos, etc., which are found native nowhere else.

In **New Zealand** and the neighbouring islands even marsupials and monotremes are absent, and the only native land mammals are two species of bat and perhaps a rat. Many of the native birds are restricted to the region, and a large proportion of them are flightless (*e.g.* the kiwi or apteryx). The reptiles also form a curiously unique assemblage.

It will of course be borne in mind that the advent of civilised man in Australasia has brought about a complete redistribution of animal life there, in respect not only of numbers, but still more of kinds. The herds of cattle and flocks of sheep now occupying

wide tracts of land, and the disastrous extent to which rabbits have multiplied, illustrate strikingly the disturbance caused by human interference with the natural balance of animal life.

Animals of the polar zones.—The increasing scarcity of plants in the higher latitudes allows only a relatively small number of animals and kinds of animals to live within the polar zones; while the severity of the winters explains the thick fur which is so characteristic of circumpolar mammals generally. As might have been expected, the animal life is on the whole more abundant near the coast, where a supply of food is obtainable from fish. Inland, the animals are mostly herbivorous.

In the **south polar zone** very few of the larger animals have yet been found. The Patagonian sea lion—one of the "eared" seals—occurring on the coasts of the southern extremity of South America and of some of the neighbouring islands, is the best known mammal. The penguins are the most characteristic birds of the Antarctic islands; they extend from the Falklands to New Zealand, and are not found further north than the Cape of Good Hope.

In the **north polar zone**, among carnivores are found the polar bear, the Arctic fox, the glutton or wolverine, the walrus and certain species of seal. An "eared" seal, known as Steller's sea bear, forms one of the chief articles of food to the natives of the Aleutian Islands, and furnishes also the materials for many of their garments. Of hoofed animals the reindeer (called in America the caribou) is of vital importance to the nomadic peoples inhabiting the tundra. It feeds chiefly on lichens and mosses, to obtain which it wanders northward in summer and southward in winter. By the races who have more or less domesticated it, the reindeer is trained to draw sledges, and its milk, flesh and skin provide food and clothing. The elk or moose and the musk ox are also circumpolar. The polar hare and the lemming (which are rodents), and the ptarmigan among birds, also belong to this zone. Reptiles are absent. Many Arctic animals hibernate during the coldest months; while in the summer their numbers are increased by migratory birds which have come north to breed.

It is interesting to note that during the glacial epoch (p. 165), Arctic animals flourished in Britain, where fossil remains of the glutton, cave bear, elk, mammoth (living on till later in Siberia) are found in caves and glacial drift. With the retreat of the ice they migrated northward, and some became extinct.

Protective coloration.—A remarkable feature of many animals

is the extent to which their coloration renders them inconspicuous among their characteristic surroundings. The advantage of thus being able to avoid being noticed by their enemies or prey—or both—is obvious. Desert animals, for example, are usually tawny in colour; the denizens of jungles are striped or spotted; and many of the beasts and birds of the snow-covered tundra are white, at least in winter.

46. THE DISTRIBUTION OF HUMAN POPULATION.

1. Dependence on climate.—Examine a population map of the world. What parts of the earth are uninhabited or have a population of less than 1 person per square mile? Which of these regions fall in the polar zones, which in the temperate zones, and which in the tropics? Which of them have an oceanic and which an extreme continental climate? If possible compare, in the case of Africa, India, Australia and South America, the population map with the rainfall map. Is the population in general greatest where the rainfall is greatest, and least where the rainfall is least, or not? What exceptional condition is found in South America? Can you explain it? Judging by population and rainfall maps of Europe, in what countries do you suppose the distribution of population is respectively most and least plainly affected by the rainfall? Contrast in this respect Spain and Great Britain.

2. Climate and trade routes.—Compare a map of prevailing winds with a commercial chart showing trade routes. How many of these routes do you suppose were originally decided by the winds?

3. Dependence on productions.—(*a*) Compare a geological and a population map of the *British Isles*. What correspondence exists between the positions of coalfields and most densely populated areas? What densely populated areas have no obvious relation to coalfields? Refer to a vegetation map of the British Isles and see whether it affords any explanation of the differences in population of the various non-manufacturing districts. Write notes of any conclusions you arrive at.

(*b*) From geological and population maps of *Europe* make a list of districts in which density of population is plainly associated with the presence of Coal Measures.

4. Dependence on geographical position. (*a*) *Alluvial plains and deltas* (pp. 147 and 149).—From the population map of the world, make a list of six rivers, the lower parts of which flow through areas

of specially dense population. In what parts of Europe do alluvial plains, or deltas, seem most obviously associated with dense population?

(*b*) *Positions of towns.*—(i) Find the positions of the following towns, and account for their names: Aberdeen,* Coblenz,† Oxford, Cambridge, Innsbrück, ‡ Edinburgh, § Cherbourg. § Examine orographical and other maps, and try to explain the special advantages of position possessed by London, Paris, Marseilles and Vienna before the introduction of railways.

(ii) Opposite what great continental river mouth does *London* stand? How is this an advantage? What advantages of water supply does London owe to the Thames and the geological structure of the London basin (p. 139) respectively? How did the Thames make it easy for London to communicate with the interior of England and with the Bristol Channel by land? How is London favoured by the estuary of the Thames? Why were the positions of Chatham and Southampton respectively inferior to that of London?

(iii) What river valleys converge on *Paris*? Which of these valleys communicate with other valleys and gaps to allow ease of access to Belgium, Germany, Switzerland, Italy and south-east France? What advantages of position has Paris over Rouen?

(iv) What geographical advantages over Toulon and Lyons respectively are possessed by *Marseilles*? What danger has Marseilles escaped by being built so far to the east of the flood-delta of the Rhone? What are the most natural routes from Marseilles to Germany, Paris and Rome respectively?

(v) What river valleys and Alpine passes give *Vienna* access to the Plain of Lombardy, the Black Sea, the Rhine Valley and the Baltic Sea respectively?

Man's dependence upon climate.—Fundamentally, mankind is quite as dependent upon plant life for food as are any animals. Nevertheless by co-operation for mutual benefit in barter and trading generally, and by the perfection which methods of communication and the transport of goods have reached, human beings find it possible to live at considerable distances from the places at which much of their food is actually grown, or their water supply is actually stored. Most English people, for example, live chiefly on bread made from wheat which was grown thousands of miles away. Being able to import also the materials required

* *Aber* (Celtic) = a confluence. † = Lat. *confluens.*
‡ *Brücke* (Germ.) = a bridge. § *Burgh* (Teut.) = a fortified place.

for clothing, dwellings and other protections against adverse weather, civilised man can, further, live under more varied conditions of climate than could be borne by any creature not so protected.

Man's relation to the great vegetation belts of the earth, though thus to some extent indirect, is none the less real; for—apart from his ultimate dependence upon plant food—he is like most other living things, plants as well as animals, in being unable to exist with ease in conditions of either extreme dryness or great cold. Of necessity, population must be always small in the deserts and in the polar zones. Dense forests, whether in the tropical or the temperate parts of the earth, also put great difficulties in the way of permanent human settlement, and are but thinly inhabited. In such regions the population is densest along the forest borders.

Of the two great factors of climate—temperature and rainfall—the latter has much the greater influence on density of population. That regularity of water supply is of the first importance in this respect is shown by the remarkable manner in which the number of persons per square mile often varies directly with the mean annual rainfall. Parts of India display this very conspicuously, and a similar correspondence is noticeable in Australia and Africa, as well as in Spain. It is natural, also, to find that the population of deserts is grouped round the oases.

Land configuration, by modifying climate, has also a more direct influence on density of population. In the tropics, the high lands are generally more thickly peopled than the valleys and plains, so far as increased altitude is accompanied by increased comfort of life. On the other hand, elevated land becomes colder and less habitable as the poles are approached, and in the higher latitudes the population is greatest at sea level. It is found that in the Alps, and in other mountainous districts where the valleys run east and west, the sunny slopes are to a marked degree more thickly populated than the shaded parts of the valleys.

Prevailing winds not only influenced the progress of geographical discovery (and hence the distribution of population) before the days of steamships, but also determined many **trade-routes** across

the sea, and so favoured the development of centres of population on these routes.

Population as controlled by productions.—Wherever food has to be sought far and wide, the population naturally tends to be distributed thinly. Thus, the inhabitants of the tundra, being compelled to accompany the reindeer as these animals wander in search of food, are nomadic; and with all pastoral peoples the necessity of searching for **pasturage** for flocks and herds brings about a similar lack of settled abodes. It is therefore in the steppe belts and the desert borders that typically nomadic conditions of life must be sought. Food, however, does not decide the distribution of population entirely, even with nomadic peoples. Dr. Nansen pointed out that the driftwood carried by the polar current down the east coast of Greenland and up the west coast is essential to the existence of the Greenland Eskimo. The curious result is that the distribution of the Greenland Eskimo is determined by the course which the driftwood takes.

In contrast with the thinness of population caused by such conditions of life, is the aggregation of human beings into populous towns and cities round sources of abundant **mineral wealth**. No better example of this could be found than in our own country; indeed, maps specially marked to show respectively the coalfields and the distribution of the population in England seem strikingly alike at the first glance. Naturally, great manufactures (often of raw materials, *e.g.* cotton, brought from a distance) have sprung up close to the spots where the all-important coal and iron are found,* and these have increased the density of population still further. Since it is in districts which otherwise furnish little or no means of subsistence that the mineral wealth of this country is chiefly found, thickly peopled areas occur here sharply contrasting with virtually unpopulated districts close by. To a smaller extent the mineral resources of the European continent have affected the distribution of its population. Again, the deserts of northern Chile owe their population entirely to the valuable deposits of nitrates and other minerals.

* Cotton manufacture also requires a moist climate, such as is found in Lancashire.

As further instances illustrating the dependence of population on productions—cases directly linked up with the horizontal and vertical distribution of plants—may be mentioned the large towns of the North Pacific coast of the United States, which flourish on the trade in **timber** obtained from the forested slopes of the Cascade Mountains and the Sierra Nevada; and also the significant fact that in the Alps the upper limit at which **grain** can be grown, and the elevations to which human settlements reach, are practically the same.

Dependence of population on geographical position.—A population map of the world shows that humanity is most closely massed together near the mouths of certain great rivers: the Yang-tse-Kiang, the Hoang Ho, the Ganges, the Nile, etc.—in all cases on extensive **alluvial plains** or deltas (pp. 147 and 149). It is to be noticed, also, that on the alluvial flats of the Meuse, Rhine, Po and other rivers in Europe, and on those of the Thames, Clyde and Mersey in Britain, the population is markedly denser than near the mouths of rivers which have not laid down these rich and fertile soils. In ancient times such alluvial flats were the centres of civilisation. Indeed it has been surmised that it was on the Mesopotamian Plain at the head of the Persian Gulf that civilisation actually originated and that wheat was cultivated first.

The sites of towns.—Since in primitive states the essential conditions for permanent human settlement must have been a supply of fresh water and the means of growing food, the almost invariable selection of sites on flat fertile ground **along the course of a river or near a spring** is easily understood. Whether the settlement grew at length to form a village, a town, or a city, naturally depended upon the possession of special advantages in addition to these essentials. Among such advantages, ease of communication with the surrounding country or neighbouring states must have been of great and increasing importance, as trading developed and made the produce of other settlements and countries available by exchange.

Any place which was specially convenient for the loading or unloading of ships (*e.g.* at the **upper limit of navigation** on a river, or at the point where a river leaves a lake),

or where for any other reason a redistribution of transported goods was necessary or advantageous, would form a natural nucleus of population. Hence the original positions of many towns (*e.g.* Newcastle-on-Tyne *). A convenient ford would often account for much early development, and when, later, it became necessary to replace the ford by a bridge, the corporate effort required would, as is usual with corporate effort, encourage the growth of the town. **Bridge towns** are consequently common, and have attained the greatest importance where, as in the case of London, the position of the bridge coincided with the upper limit of navigation.

Of even greater consequence than a ford would be easy access to river valleys, or a position on the coast conveniently situated for intercourse with other lands. The gaps at the heads of valleys form natural gates (Figs. 16 and 149), which join valley to valley to form a net-work of highways throughout the country. The growth of a town (Leeds) at the foot of the Aire Gap was natural. Clearly, other circumstances being favourable, a position on which many important valleys converge is an ideal site for a town. Such **confluence-towns** are illustrated by Reading, Oxford, Coblenz, Lyons, and St. Louis.

The commercial and strategical advantages of a position on a **strait** are obvious. They account for the existence of Constantinople, Gibraltar, Aden, and Messina.

It is an instructive exercise to examine the positions of, say, various **European capitals**, in the light of such considerations as those just referred to, and with the help of good orographical maps. *London* is thus seen to have had the initial advantages of an alluvial flat not liable to flooding; of a bed of gravel supplying good water in plenty; of a position at the head of navigation which could easily be bridged; of a river valley branching in many directions and cutting through ranges of hills, giving access to the heart of the country and even communicating with rivers (*e.g.* the Severn) leading to other seas; of a position facing a great population and the mouth of a great river on the continent; of an estuary capable at the same time of admitting large ships and of affording

* As larger ships became common these towns would naturally be superseded in many cases by new towns lower down the river, where the water was deeper.

protection from attack by sea. Though other positions in England possessed certain of these advantages in larger measure, only London possessed them all, and therefore grew in wealth, importance and population at a greater rate than its rivals.

Similarly, an attentive study of the position of *Paris* will show its superiority, for example, to Rouen, in respect of the river valleys it commands—avenues to Holland, Belgium, Germany, Switzerland, and Italy, besides south-eastern France. Again, *Marseilles*, which, by the way, avoids the risk of inundation by its position to the east of the Rhone delta, has manifest advantages not possessed by Lyons on the one hand or Toulon on the other. Examples might be multiplied indefinitely.

As a final instance of the influence of geographical position on density of population may be mentioned the fact that in the circumpolar regions, it is apparently the length of the darkness of winter (which prevents hunting and fishing), rather than the great cold, which fixes the limit of human settlement.

It is certain that the distribution of mankind over the earth has been modified considerably by that of certain insects which are responsible for the spread of various diseases. Sleeping sickness, carried by the tsetse fly, has rendered many fertile tracts of tropical Africa uninhabitable; and malaria, spread by a species of mosquito, is believed by some authorities to have been a material cause in the fall of ancient Greek civilisation.

EXERCISES ON CHAPTER XVII.

1. Scotland presents an admirable example of the effects of a country's physical geography on the industries of its inhabitants. Prove this statement. (L.J.S.)

2. Explain how climatic differences affect the occupations and distribution of the peoples living (*a*) in south and east Asia, (*b*) in central Asia, and (*c*) in north Asia. (Prel. Cert.)

3. Show how the natural productions change as we proceed from south to north (*a*) from Cape Matapan to Hammerfest, and (*b*) from Cuba by Toronto to Hudson Bay. Account for the variation in each case. (Cert.)

4. Indicate the effects which the *position* and the *build* of either Australia or India or Spain have had upon its climate, productions, the density of its population, and its trade. (Prel. Cert.)

5. Explain fully why, in Monmouthshire, contrary to the general rule, the hilly portion is more thickly populated than the plain. (Prel. Cert.)

6. "The settlements of man are less dependent on physical conditions than in former times." From your knowledge of the British Isles show how you can justify this statement. Deal fully with any one instance. (Prel. Cert.)

7. Explain fully: *deciduous forest*, *pine forest*, and *jungle*. Mention some countries in which examples of each may be found, and name some of the wild animals living there. (P.T.)

8. Compare the occupations of the Esquimaux with those of the natives of Patagonia and the life of the inhabitants of Central Africa with that of the inhabitants of Central Australia. (P.T.)

9. What reasons can you give for the counties of Durham, Glamorgan, and Lancashire being thickly populated as compared with Cambridge, Cornwall, and Merioneth? (P.T.)

10. Indicate the influence of climate in determining (*a*) the parts of the world inhabited by nomadic races, (*b*) the wheat growing areas of the British Isles, (*c*) the regions of large coniferous forests in Europe. (Prel. Cert.)

11. Taking Europe and Africa as one land mass, compare its physical features, climatic zones, and characteristic animals and plants with those of the continent of America (North and South). (Cert.)

12. Show how the distribution of the population in Wales is related to the physical features and natural resources of the country. (C.S.)

13. State carefully the situations of Paris, Marseilles, and Lyons, and point out how their growth has been aided by their situation. (J.B.M.)

14. Explain, as fully as you can, why the lowland regions of the temperate zone are the most suitable for habitation by civilised man. Give examples illustrating your answer. (O.J.)

15. Towns are often found at the following places: (*a*) at the junction of two rivers, (*b*) where a river leaves a lake, (*c*) at the head of ocean navigation of a river. Name two towns to illustrate each of these cases, and describe the position and importance of each town. Why is it less important for a town to stand upon a river than it was a hundred years ago? (C.S.C.)

16. Towns frequently occur at the following places: (*a*) at the lowest point at which a river is bridged, (*b*) where two rivers join, (*c*) at the head of an estuary. Name two towns to illustrate each of these cases, and describe the position and importance of each town you name. What has been the effect of modern developments in shipping upon the class of towns mentioned in group (*c*)? (C.S.C.)

17. Describe the present distribution of the population of England and Wales, and contrast it with that existing before the Industrial Revolution. (J.B.M.)

18. State carefully which portions of Asia are most thickly populated, and which portions are most thinly populated, and account for the facts. (J.B.M.)

19. Discuss briefly the chief geographical features which determine the occupations of a people and the density of population. Illustrate by reference to definite regions. (N.F.U.)

20. What are the characteristic features to be remembered about the animal and vegetable life of (*a*) the Cold Regions, and (*b*) the Tropics? Mention the chief countries belonging to each region. Show by examples from these regions that the distribution of deciduous forests and evergreen woods is determined by altitude as well as by latitude. (P.T.)

21. Where are the grass lands found in Asia? How do you explain this? What is the chief occupation of the people on the great grass lands of Asia? Why? (L.J.S.)

22. Contrast the distribution of population in Scotland with that of the population in Ireland. What geographical or economic conditions explain the difference? (L.M.)

23. In what parts of the world do we still find true nomadic tribes? Show how their manner of life is controlled by their environment. (L.M.)

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